Tree Improvement Master Plan For Ontario

Ontario

Ministry of Natural Resources

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EXECUTIVE SUMMARY

The objective of the Tree Improvement Master Plan for Ontario is to provide a comprehensive action plan for the Ministry of Natural Resources. This document describes the rationale and basic principles of tree improvement, breeding programs for the priority species, and gives an example of a simple cost/benefit analysis. The plan is intended to give direction to field offices who are or will be involved in implementing a tree improvement program. Reviews and updates of the plan will occur at least every five years, or earlier if appropriate.

The overall goal of Ontario's Tree Improvement Program is to produce faster-growing and better quality trees by improving the genetic potential of the stock used in artificial regeneration. The tree improvement strategies are divided into two levels of activity; the basic program and the intensive program, each with specific goals.

Basic Program Goals: Effective immediately the genetic quality of all new forests will be maintained at a level equal to or better than that of the forests they replace, while aiming for a modest increase in genetic quality through appropriate seed source control.

Intensive Program Goals: A significant increase in both production and quality of plantations will be achieved and sustained for the most commercially important species by planting trees which will be genetically enhanced, by means of repeated cycles of selection and breeding, on the most productive sites.

Current provincial priorities rank commercial species in four priority groups for intensive programs: (1) black spruce and jack pine; (2) white spruce, white pine, (3) tamarack and Norway spruce; (4) exotic and hybrid larch, hybrid poplar, black walnut and other species. Regional species priorities may vary.

The strategies chosen for implementation in Ontario are based on the most current theories of tree breeding and forest genetics integrated with the current levels of knowledge concerning Ontario's species and conditions. The basic program encompasses both natural and artificial regeneration by ensuring that seeds originate locally from the best trees and the best stands. The intensive programs encompass seed orchards, selective breeding and clonal forestry. The intensive programs offer the greatest potential for genetic gain, on the order of 16 per cent or greater; they also require a greater commitment of economic and human resources.

INTRODUCTION

The government of Ontario has made a commitment to maintain the productivity of the province's forests by regenerating the cut and burned productive forest areas. This commitment complements one of the purposes of the Forest Management Agreements. With the advent of these agreements, the areas being regenerated have been increasing at a dramatic rate and the number of seeds and the number of trees required annually have risen and will continue to rise until the 1990's. Since the costs of artificial regeneration are high and since the use of genetically improved material will produce forests of better quality and increase the usable yields, it makes good economic sense to accelerate the tree improvement program. If the production targets of the future are to be met and the predicted shortage of wood reduced, more support will be needed for the selection of **superior trees***; for the establishment and maintenance of **breeding orchards, production orchards**, and clonal propagation orchards; and for the establishment, maintenance, and evaluation of MNR test areas. This need is recognized by the Ministry of Natural Resources, for, in the Forest Resources Group, **tree improvement** is one of the high priority programs. This need has also been recognized by several Ontario forest industries, which recently, in co-operation with the government, established the Ontario Tree Improvement Council.

In order to improve the yields and the quality of wood through tree improvement, it is important to have a continuing program with both short-range and long-range goals. In the short term, some **genetic gain** can be obtained relatively quickly and at a modest cost. Such gains are significant when there is a large artificial regeneration program. But to get the much greater benefit obtainable from genetics, there must be a long-range breeding program, with goals that are established at the outset. To reach these goals, substantial planning is necessary especially since the genetic material initially selected for the program will be an important part of the foundation for future generations of trees.

This is the first comprehensive document detailing an overall tree improvement plan for the MNR. It describes the rationale, some basic principles, breeding approaches for several different species and purposes, and a cost and benefit analysis, all of which will impact on the direction of tree improvement for the province.

*Boldface in text indicates term listed in this glossary.

HISTORY AND CURRENT STATUS OF TREE IMPROVEMENT IN ONTARIO

Forest genetics and tree improvement work in Ontario was initiated in the 1920s by scientists working for the Canadian Forestry Service at the Petawawa Forest Experiment Station. Efforts by the provincial government were started by the former Department of Lands and Forests in 1946. This early work dealt largely with research aspects of tree improvement and forest genetics. Operational tree improvement started in the 1950s, but the program grew at a relatively slow pace through the 1950s and 1960s. As increasing emphasis was placed on tree improvement during the 1970s the program developed more rapidly. The staff originally assigned to the operational program had insufficient background in tree improvement and as a result, the planning of the work was not only incomplete but often misdirected. Many of these shortcomings were recognized during the 1970s and have since been reduced or eliminated. Recently, steps have been taken to give the field staff more training in tree improvement technology, including information about the hazards of not applying sound genetic principles at the outset of a program.

Since 1980, there have been some important changes of emphasis. Complete tree improvement programs are being developed for commercially important species. Seedling seed orchards are being established for both jack pine and black spruce; clonal orchards continue to be established for white pine and white spruce; more effort is being devoted to clonal propagation through the rooting of cuttings; and changes have been made in the design of **seed orchards** and genetic tests, and in **mating designs**.

PRINCIPLES AND PRACTICES OF TREE IMPROVEMENT

Ideally, the steps in tree improvement should be to (1) determine the amount of **genetic variation** and its distribution within each species or population, (2) capture the favourable parts of that variation by selecting stands and/or trees with the desired **characteristics**, (3) package and mass-produce the favourable genetic variation either as seedlings or as **vegetative propagules**, (4) recombine the genetic variation to obtain additional genetic gain in future generations. The following sections briefly relate these operations to basic genetic principles.

STEP 1: ASSESSING GENETIC VARIATION

The genetic structure of a species is the distribution of genetic variation among (1) widely separated geographic populations, (2) local populations, (3) stands within a local population, and (4) trees within a stand. Genetic architecture experiments can determine the relative amount of genetic variation at various levels of species organization, and how much of the variation is usable under sexual and clonal selection. The genetic structure of a species will determine how (or whether) its stands should be managed for seed production, how individual trees should be selected, and how breeding programs should be designed.

STEP 2: CAPTURING GENETIC VARIATION

Geographic Variation

Stands of a given species that grow in physiographically distinct areas often differ genetically owing to local environmental selection pressures. Through time, these populations have become genetically different and well adapted to the area in which they are growing. Since the genetic differences between adjacent populations or stands are generally much less than more widely spaced stands, seeds should be moved only a limited distance. It is dangerous to move seeds too far from their source unless there is evidence that introduced material is climatically adapted.

Population Variation

Within any physiographic region, there are several genetic processes at work that can produce different genotypes and, consequently, genetically different populations. If the better populations can be identified through testing, they can be used to advantage by establishing **seed-collection** and **seed-production areas** in suitable stands.

Individual-Tree Variation

In any genetically variable population, there is considerable variation from tree to tree. For any given trait, and particularly for combinations of desired traits, some trees will be better than others. This premise is the basis for the **selection** of individual trees and the establishment of seed orchards.

The most important traits selected for in the Ontario program are (1) height and diameter growth rate, (2) stem and branch form, (3) wood quality with particular attention to specific gravity and (4) adaptability.

Heritability and Genetic Gain

The physical appearance of a tree, i.e. its **phenotype**, is the combined outward expression of its genotype and the **environment** in which it has developed. **Heritability** is the term applied to the ratio of genotypic variance to total phenotypic variance. The total variability in some traits is more influenced by genetic variability than by **environmental variability**, i.e. such variation has a higher heritability. For example, the environment in which trees grow has little effect on branch angle; most of the variation in branch angle among trees is due to the differences in genotypes. Thus, the trait is said to be highly heritable. On the other hand, diameter growth has relatively low heritability, as this is very much affected by the site and the proximity of neighbours, even though genetic variation influencing diameter is large and can exert strong effects in a uniform environment. For traits with a high heritability, the method of selection and testing can be simple; for traits with low heritability, efficient methods are usually more complex.

Genetic gain depends on three factors: (1) the availability of variation, measured as the phenotypic standard deviation (Symbol σp), (2) the heritability of the trait being selected for (symbol h^2) and (3) the size of the selection program, measured as the selection intensity (i.e. proportion selected; symbol i). If these three are known or can be estimated, the genetic gain (symbol G) can be predicted using the numerical relationship:

$$G = i \times h^2 \times \sigma p$$

STEP 3: PRODUCTION AND UTILIZATION

The third step involves management of selected material to produce sufficient quantities of genetically enhanced planting stock. One method, collection of seeds from superior natural stands, was mentioned above. There are currently two additional options for this phase that provide greater genetic gain: (1) mass **vegetative propagation**, and (2) seed orchards.

Vegetative propagation is a powerful tool breeders may use in tree improvement programs. A given genotype may be replicated exactly by any one of a number of methods, although grafting is the most common method. However, grafting is not suitable for mass production of planting stock or for stock intended for genetic tests. Rooted **cuttings** are the preferred type of stock for production plantings.

Seed orchards are plantations of selected trees managed to produce early and abundant crops of genetically improved seeds for nursery or container stock. The selected trees in a clonal seed orchard may be grafts or rooted cuttings. The trees in a seedling seed orchard are usually seedlings grown from seeds of the selected parent(s).

STEP 4: ADVANCED GENERATION BREEDING

The main objective of the tree breeder in an operational program is to produce populations from which cumulatively better genotypes may be selected for production orchards or for rooted cutting programs. In a dynamic multi-generation breeding program, periodic contraction and expansion of populations during alternating cycles of breeding, testing and selection (to increase the frequencies of favourable **alleles**) is known as recurrent selection and is the backbone of any long-term improvement hopes.

SPECIES PRIORITIES

The choice of species for a tree improvement program is based on several factors. The primary one is the commercial importance of a species, particularly when it has a large artificial regeneration program. Two other factors are the variability of the species in important characteristics and the heritability of those characteristics.

The priorities differ from one administrative region to another and even from one district to another. Table 1 shows the overall provincial effort for the various species, which are listed in four groups with the percentage of the total resources for tree improvement that should be devoted to each.

Table 1: Species for Improvement, in Order of Provincial Priority

Group	Species	Effort (%)
I	Black Spruce Jack Pine	70
II	White Pine White Spruce	15
III	Tamarack Norway Spruce	7.5
IV	Exotic and hybrid larch Blister-rust-resistant white pine hybrids Hybrid poplar Black walnut Other selected species	7.5

Black spruce and jack pine have top priority because 80 per cent of the current artificial regeneration effort is expended on these two species; both have much variability (with useful genetic components). Through genetic improvement and silvicultural management, the rotations of these species can be shortened by more than 20 per cent (that is, produce the same volume in 20 per cent less time). In addition to volume, the quality of jack pine can also be greatly improved by modifying stem and branch form, as well as the characteristics of the wood.

White pine and white spruce are important in southern and central Ontario. Since both are valuable lumber species, gains made in stem form and wood quality will be significant. The rotations for both are long but can be reduced through selection, testing and silvicultural management.

Tamarack is a species with unrealized potential, although it is not at present in favour with most of the forest industry. It is a desirable species for regeneration, but few trees have been planted in part due to a shortage of seeds. The wood and pulp characteristics are not as good as those of the preferred species, but they are more than adequate. Some of the problems can be reduced if young, fast-grown trees are used for certain pulping processes rather than very old, slow-grown trees. With a proper tree improvement program and intensive management, a suitable product can be produced. Tamarack is not, and should not be considered, a replacement for spruce or pine, but because of its capacity for rapid early growth it should be considered as a stopgap to overcome some of the predicted short-term wood supply shortages.

Norway spruce has great potential as a long-fibred, short rotation species for southern Ontario. Early results from small field trials indicate that Norway spruce is capable of out-producing white spruce on a number of sites. A 25-year rotation for pulp logs is quite possible.

Although the remaining species and species **hybrids** are placed in a fourth category, they should not be totally neglected as they do have special attributes that can contribute to the provincial artificial regeneration program. For places where white pine is appropriate but blister rust is a problem, a program should be developed that would provide rust-resistant stock. A limited collection of genotypes is already available through the work underway at the Ontario Tree Improvement and Forest Biomass Institute (OTIFBI) that could serve as a foundation for an expanded program.

Poplar (specifically the hybrid program) is placed on the list of priorities because of its prominence in the Eastern Region, the amount of genetic variability in the species and their hybrids, and the amount of development work that has already been successfully devoted to the hybrid program.

Black walnut is one of the few species of Ontario hardwoods that can justify a tree-improvement program. Several hundred thousand walnut trees are planted annually. Since there is substantial genetic variation in the species, considerable gains can be made in growth rate and in stem and branch characteristics. The return on investment could be very lucrative since the wood is extremely valuable for furniture.

Other hardwoods, such as the aspens, maple and yellow birch, are not considered priorities for tree improvement because of their relatively low economic priority and also because most of them regenerate primarily by natural means. For that reason, the emphasis should be on good stand management to ensure good-quality regeneration and the maintenance of a satisfactory **gene pool**. Only small quantities of this group of species are planted, and survival in many of the plantations is very poor. Until good silvicultural management is practised and until the planting program warrants, tree improvement cannot be economically justified.

Although red pine still plays a large part in Ontario's artificial regeneration program, there is no strategy proposed because the amount of genetic variation is too low to be effectively useful. Any attempts to improve the species would not be cost-effective.

TREE IMPROVEMENT PROGRAM GOALS

The overall goal of Ontario's Tree Improvement Program is to produce faster growing and better quality trees by improving the genetic potential of stock used for artificial regeneration. Ontario's Tree Improvement Program is subdivided into two levels based on intensity of effort, immediacy of results and expectations for genetic improvement.

BASIC PROGRAM

Silvicultural practices may strongly influence the genetic quality of new-growth forests. Cutting practices that were, in effect, dysgenic selection (undesirable trees left to regenerate the site), have in some instances severely eroded the local gene pools of forest tree species. Inadequate attention to the use of appropriate sources of seeds for regeneration has also exacerbated the problem. Good intensive forest management practices dictate that, as a minimum standard, the genetic quality of the forests be maintained at the status quo.

Basic Program Goals: Effective immediately, the genetic quality of all new forests will be sustained at least equal to the level of the forests they replace, while aiming for a modest increase in genetic quality through appropriate seed source control.

INTENSIVE PROGRAM

Substantial increases in the genetic quality of reforestation stock can be obtained through intensive breeding programs. When coupled with intensive management systems, these trees will yield impressive gains in volume and in product quality. As stated earlier, the greatest dividends will be returned from using the best quality stock on prime sites.

Intensive Program Goals: A significant increase in both production and quality of plantations will be achieved and sustained for the most commercially important species by planting trees which will be genetically enhanced, by means of repeated cycles of selection and breeding, on the most productive sites.

Short term objectives of the intensive program include:

- By 1995, black spruce and jack pine planting stock for prime sites will originate from orchard material.
- By 2000, white pine and white spruce planting stock for prime sites will originate from orchard material.
- By 2000, clonal forestry programs will account for approximately 30 per cent of the planting stock for black spruce and jack pine.*

In regions where a Group III or IV species may be a high priority, the target is the year 2000 for improved stock.

*Refinements of techniques are still required before jack pine clonal forestry can be done on an operational scale.

TREE IMPROVEMENT STRATEGIES

Breeding alternatives have been examined in the context of Ontario's requirements and conditions, and tree improvement strategies have been formulated. The strategy recommended for each depends on both biological and economic factors. Among the important biological considerations are: ease of reproduction, either sexually (with **viable** seed) or vegetatively (by grafting and rooting of cuttings); ease of **scion** or seed collection for seed orchards; time from the establishment of an orchard to the onset of flowering; ease of cutting production; quantity of planting stock required; and **periodicity** of collectable cone crops.

The tree improvement strategies described below are divided into one basic and three intensive programs. The following pages are meant to provide procedural guidelines and not operational details, which are, or will be, available in manuals and policy and procedures bulletins. Information is also available from the staff of the Tree Seed and Forest Genetics Unit of Forest Resources Group (TSFGU), from forest geneticists at OTIFBI, and from the tree improvement specialists in the field.

BASIC

STRATEGY I — SEED SOURCE CONTROL

The basic program is the minimum work required for all native species that are regenerated artificially, including those that do not merit an intensive tree breeding strategy either because there is not enough variation in the species (e.g. red pine) or because the regeneration program is too small (on a regional, or more localized basis) to justify the establishment of production programs (seeds or rooted cuttings). It will also provide material to the regeneration program for the priority species until seeds or cuttings are available from the intensive programs.

Strategy Essentials

1. The basic program defines the minimum work required for each species used in the artificial regeneration program.
2. Seeds for all species will come from identified sources.
3. Enough seeds, seedlings or rooted cuttings will be available for each **planting zone** so that no planting material will have to be moved far from its place of origin (later, with sufficient testing, some may be moved).
4. No seeds, seedlings, or rooted cuttings will be moved from one planting zone to another unless permission is obtained from the appropriate MNR regional office and from the TSFGU.
5. Seeds will not be collected from plantations unless the original source is known and appropriate. If the source is unknown, the plantation must be at least one-third rotation age and then thoroughly

evaluated and approved by the TSFGU before any seeds for regeneration purposes are collected from it.

6. All seed-collection and seed-production areas will be in natural stands or in plantations that have met or exceeded criteria in 5. above.
7. All gene pool reserves, seed-collection and seed-production areas will be regenerated with their own seed source.

Procedural Guidelines

SEED SOURCE

The first step in operational tree improvement is to control the source of seeds. The province has been divided into **seed zones** (Figure 1) for this purpose. Initially, planting zones will correspond to seed zones until deployment guidelines are verified through tests.

Unless test results are available to prove otherwise, **local seeds** are the safest because the trees from which the seeds were collected have survived local conditions through many generations of natural selection. Neither seeds nor seedlings will be moved from one seed zone to another unless permission is obtained from the MNR regional office and from the TSFGU. Seeds will be collected from production plantations only if the source is known and appropriate or if the plantation is at least one-third projected rotation age and outperforming comparable local stands or plantations.

GENE POOL RESERVES

Gene pool reserves will be identified in selected areas for species whose gene pools have been severely eroded by factors such as past land use patterns (e.g. white pine and white spruce in southern Ontario). In addition, gene pool reserves may be identified for selected large native populations. Gene pool reserves will be used to provide seeds for planting and seeding programs, including the re-establishment of the reserves themselves and adjacent areas when they are cut. Particularly in southern Ontario, it may be necessary to manage gene pool reserves cooperatively with private landowners, or even to collect material for reserve establishment on alternate sites in order to ensure conservation of the genetic resource.

SEED-COLLECTION AND SEED-PRODUCTION AREAS

During the next few years much of the seed supply for artificial regeneration will come from these phenotypically superior stands. After the production orchards start to flower and can supply the seeds needed by nurseries, these areas will continue to be managed to meet some or all of the requirements for the direct seeding work. When the designated seed-collection and seed-production areas are cut and restocked, they will be regenerated with seeds from the same population. The surrounding areas will also be regenerated with seeds from the same source.

Figure 1: — *Seed zones of Ontario.*

Whenever possible, all seed-production areas and seed-collection areas should be natural stands that have not been high-graded or the gene pool disturbed (those that have should be considered as gene pool reserves, not seed-production areas). To meet the requirements in southern Ontario, it may be necessary to establish some plantations, whose seed source is known, as seed-production areas. If the source is unknown, the plantation must be at least one-third projected rotation age and out-performing local controls before being designated as a collection or production area.

INTENSIVE

STRATEGY II — THE SEEDLING SEED ORCHARD

The seedling seed orchard is one of the three intensive strategies adopted for Ontario's Tree Improvement Program. In this approach, trees with desired characteristics are selected from the natural populations in each **breeding zone**. Open-pollinated seeds are collected from those trees and germinated; the resultant seedlings are planted in a production seed orchard and in at least two **family test** plantations. In addition to the seeds, a few scions are collected from each parent tree, grafted, and placed in a clonal breeding orchard. Results from the family tests will be used to eliminate the members of the poorer families in the production orchard, thus improving the average quality of seeds then produced. Some trees selected from the family test will also be used to establish the second-generation orchard. As the breeding orchard starts to flower, **controlled pollinations** will be made according to a predetermined mating design. The resulting fully **pedigreed** progeny will be planted in field evaluation tests to form the basis for future high-intensity breeding programs, and where needed, to serve as **donor** stock for a **clonal forestry** program. Figure 2 outlines the steps in this program.

The seedling seed orchard approach is proposed for the first generation of improvement for species that have several of the following characteristics:

1. Graft **incompatibility** or little success in grafting scions from mature trees.
2. Difficulty in selecting phenotypically superior trees in natural stands (i.e. the stands are unevenly spaced, are uneven age, or overmature stands, particularly where the primary selection criterion is rate of growth).
3. **Serotinous** or semi-serotinous **cone habit** (which allows cones to be collected from widely-dispersed original trees over a long period).
4. Relatively frequent and abundant cone crops and consequently little loss of time in obtaining seeds from the original selections to start the orchard program.
5. At least average stocking level in the natural stands (therefore each seed collected has less chance of having been **selfed**).

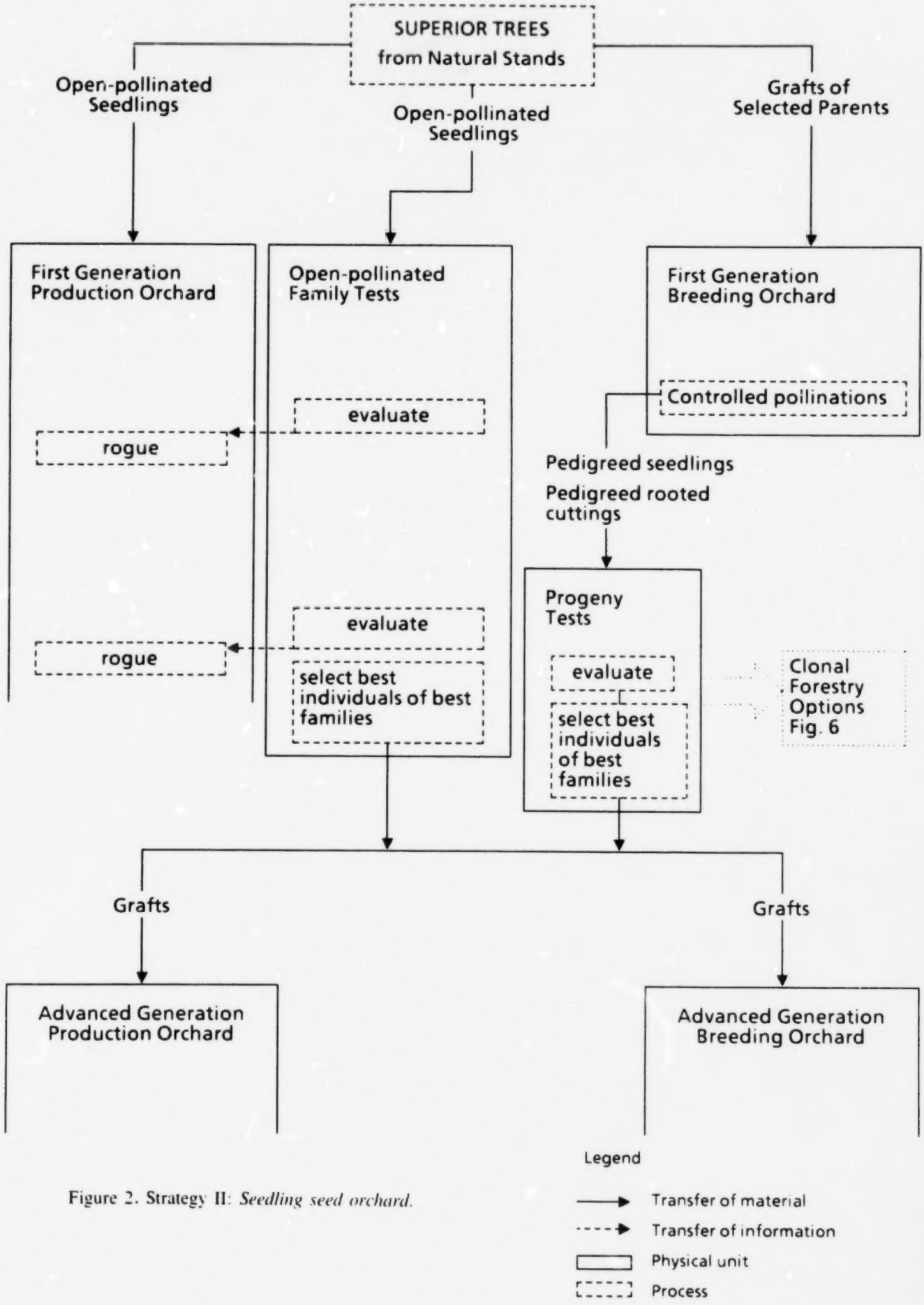


Figure 2. Strategy II: *Seedling seed orchard.*

6. An urgent need for large quantities of seeds for the artificial regeneration program (it is quicker and less expensive to grow large quantities of seedlings to establish an orchard than to graft large numbers of scions).
7. **Precocious flowering habit** (relatively few years from germination to onset of flowering, thus little time would be saved by grafting mature scions, which tend to flower early).
8. Prolific flowering habit (for many species, although mature grafts flower earlier than seedlings, they produce fewer flowers, once the seedlings have reached full sexual maturity).

Strategy Essentials

1. A minimum of 450 selections per breeding zone will be made in order to obtain the 400 open-pollinated families required for the orchard.
2. The first-generation production orchards will be established with seedlings following the recommended design or one meeting specified minimum criteria.
3. A minimum of two (preferably three-to-four) open-pollinated-family tests will be established according to the recommended test design in each seedling seed orchard.
4. A breeding orchard will be established for all selected trees.
5. Selective breeding will be done after the first evaluation of the family tests according to a specific mating design.
6. Each pedigreed-family-evaluation plantation will be established at a minimum of three different locations according to the recommended test design.
7. Selections from the open-pollinated-family tests and the pedigreed progeny tests will form the foundation stock for the advanced-generation orchards.
8. The clonal option (which will probably use rooted cuttings) will be implemented whenever economically and biologically feasible, especially in the early stages of seed production in the orchards in order to use the genetically improved seeds more efficiently.

Procedural Guidelines

SELECTION OF SUPERIOR TREES

A minimum of 450 trees (400 and 50 extra in case of insufficient or non-viable seed) will be selected for each seedling seed orchard to be established. The trees selected will be well distributed throughout the breeding zone and, to minimize the selection of relatives, no more than one tree will be chosen from every two hectares and no two selections will be closer than 300 m apart. (Any relaxation of this restriction will need approval of the TSFGU). The best phenotypes will be chosen according to the selection criteria for the species. Both cones and scions will be collected from each tree.

FIRST-GENERATION PRODUCTION ORCHARD

The first-generation production orchard will be established with seedlings from at least 400 different selected trees per breeding zone. The size of each orchard will depend upon the projected planting requirements for its planting zone and the estimated per tree production of viable seeds. No orchard should be smaller than eight hectares. Each orchard will have a minimum of 50 blocks, each divided into four sets of 100 trees. Each 100-tree set will contain one seedling from one of each of 100 different families. The 100 seedlings will be planted in 25 four-tree clusters in a completely random fashion. Each 4-set block will, therefore, contain one seedling from each of the 400 different families. The planting layout is shown in Figure 3.

The first **roguing** of the seedling orchard will be delayed until the four-tree clusters start to close and when branches are beginning to die on one or more sides of the trees. For this reason it is important that the family tests be established quickly, to provide the basis for this first roguing from trees as old or even older than their seed orchard sibs.

The criteria for site selection, site preparation and orchard management are detailed in the *Operational Guidelines For Tree Improvement* prepared by the TSFGU.

In the early years of the orchards, the seeds they produce will be insufficient to meet planting requirements. If it is economically and biologically feasible, these seeds should be used to grow donor stock for the production of cuttings for the clonal forestry program (Strategy IV).

(OPEN-POLLINATED) FAMILY TESTS

It is recommended that three or four (a minimum of two is mandatory) family-test plantations be established for each seedling seed orchard. There must be time allowed for the development of these test plantations in order to provide reliable information on which to base the roguing of the orchards. A problem that has arisen is the difference in growth rates between the intensively managed production orchards and the much-less managed family tests.

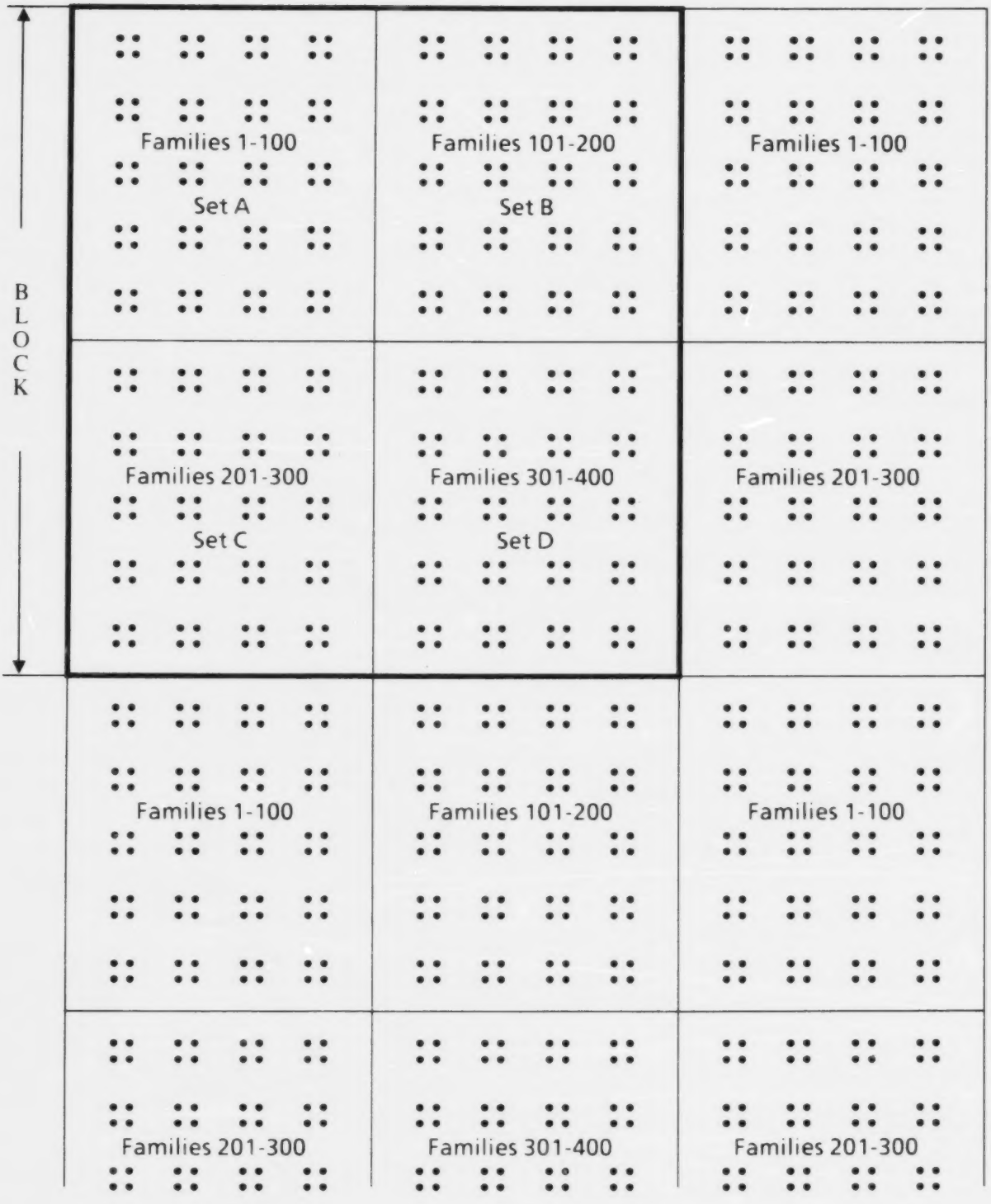


Figure 3. *Layout and Design of Seedling Seed Orchard.*

Two ways of reducing the problem are suggested. The first is to establish the orchard simultaneously with the family tests but not to water and fertilize the orchard any more than is necessary for the first two years after establishment. This would minimize the height differences between the orchard and the tests, yet maintain a high survival rate in the orchard. A second alternative is to establish the test one or two years in advance of the production orchard. Other alternatives may be possible, but these alternatives would not be acceptable if the tests would no longer be representative of typical field growing conditions. The family tests must be managed the same way as are good production plantations.

The planting design for the family tests will be 32 blocks of single-tree plots with families in subsets that replicate the orchard layout. Although marginally more difficult to establish and to map, this design is much more efficient (such that fewer trees need to be planted, fewer trees need to be measured, and the genetic information obtained is more reliable) than is the conventional multiple-tree contiguous-plot design.

The trees will be measured and evaluated when competition among the four trees of most clusters in the production orchard becomes a concern. This may be on the order of five to seven years depending on species, intensity of orchard management, etc. The trees will be rated for survival and growth (stem and branch form for some species) and the families ranked accordingly; the ranking will form the basis for the orchard roguing. Subsequent evaluations will be done for further roguing of the orchard and for the selection of material for the second-generation production and breeding orchards.

BREEDING ORCHARD

Three to five **ramets** of each selection will be planted in row plots to produce a breeding orchard. When possible, **breeding halls** should be used in order to shorten the time to flowering and to improve the flowering capacity of the ramets, particularly if a significant amount of pedigreed material is to be produced for a clonal forestry program.

Selective breeding will start immediately after the first evaluation of the family tests. The breeding population will be **sub-lined** and one of several appropriate mating designs will be used for breeding within lines. The use of sub-lines enables the breeder to reduce the problem of **inbreeding** in future production populations. To reduce contamination of the production orchard from unwanted genotypes, the breeding orchard should not be located near the production orchard. (Since the pollinations are controlled in breeding orchards, these orchards can contain clones from more than one breeding zone).

PEDIGREED-FAMILY-EVALUATION PLANTATIONS (PROGENY TESTS)

The material for the **progeny tests** will be obtained from the controlled pollinations made in the breeding orchard. The primary purpose of the progeny tests will be to provide material for the advanced-generation production and breeding orchards.

A second purpose for some species will be to provide material for a clonal forestry program in order to get improved stock to the field more quickly. Each set of sub-lined families will be planted on a minimum of three different field sites. Details on the establishment of these tests are being prepared and will be available as a procedural bulletin.

If not enough seed are available from the controlled crosses, or if better information is needed on the genotype x environmental interactions, the seedlings can be cloned and clonal-progeny tests established. Since these tests will be used for second-generation selections, enough clones per family must be produced so that the numbers of clones to select among are sufficient to provide a satisfactory selection differential.

ADVANCED-GENERATION PRODUCTION ORCHARDS

There are several ways of developing second-generation and subsequent advanced-generation production orchards. The current philosophy is to develop a clonal rather than a seedling production orchard because of the greater genetic gains possible and because many of the reasons for establishing first -generation seedling orchards may be no longer compelling in the second generation. Also, greater selection reliability can be attained in even-aged, evenly spaced plantations growing in a relatively uniform environment in statistically sound designs.

Selections for the second generation will be made in the progeny tests as soon as reliable family ranks are available. (To reduce the time between generations, it is essential to promote early flowering in the breeding orchards, so that crosses can be completed and the progeny tests established quickly.) The selections will be made from the various sub-lines created by the crossing program in such a way that inbreeding in the production orchard will be eliminated. The design and layout of the production orchard will be decided when the selections are made.

STRATEGY III — THE CLONAL SEED ORCHARD

In the second of the three intensive strategies, the clonal seed orchard approach, trees will be selected primarily from natural stands (occasionally from plantations if not enough natural selections are available) in each breeding zone. In this strategy, grafted scions from these trees will be used in both the production orchards and the breeding orchards. As the breeding orchard starts to flower, controlled pollinations will be made according to a specific mating design and the pedigreed families will be planted in three to four field evaluation plantations. The tests will be used to evaluate the first-generation production orchard and then to provide foundation stock for the second-generation orchards (Figure 4). An alternative open-pollinated-family test alternative is discussed further on in this section.

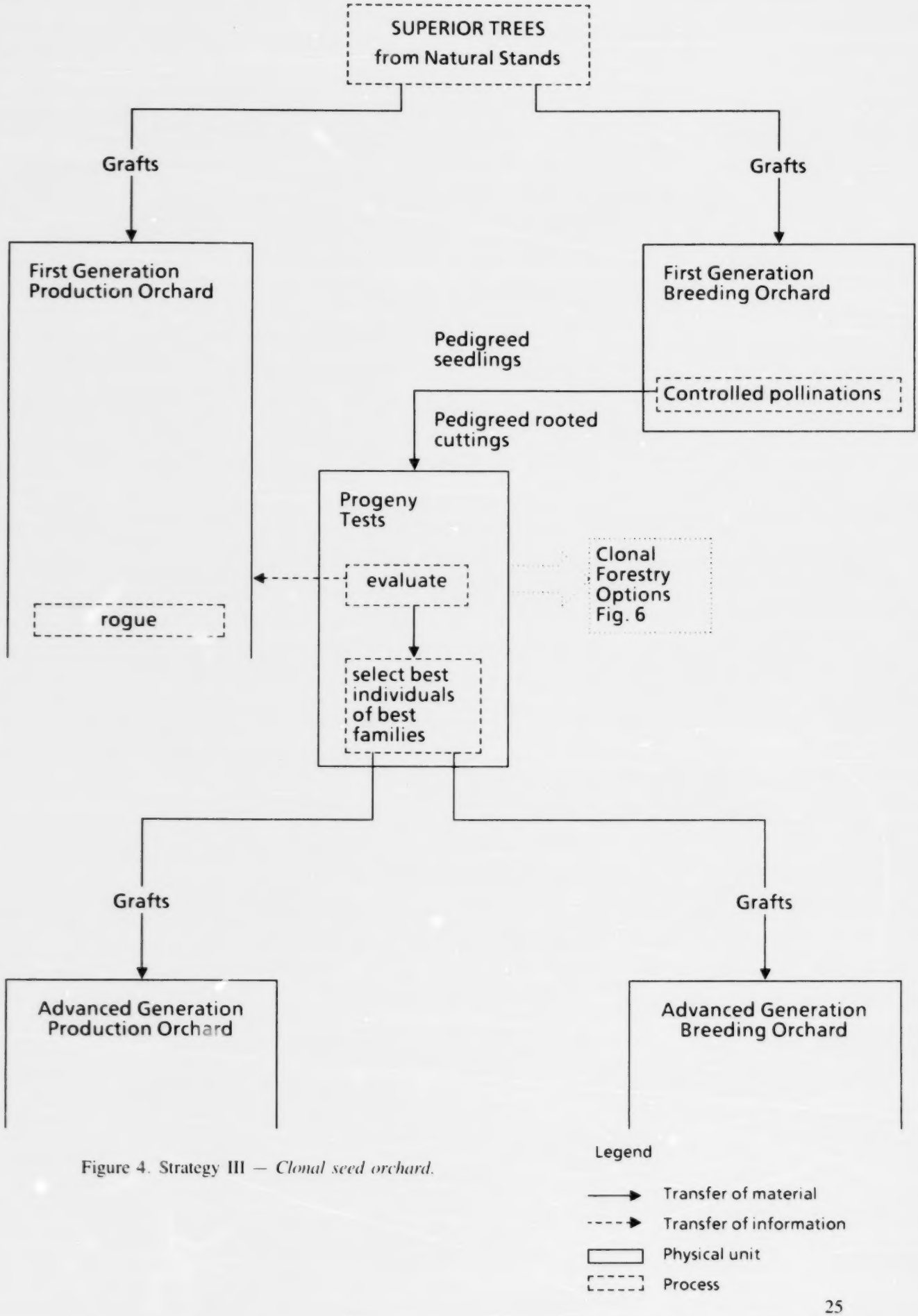


Figure 4. Strategy III — *Clonal seed orchard.*

The clonal seed orchard approach is proposed for the first generation of improvement for species that have several of the following characteristics:

1. Graft **compatibility**, especially when grafting scions from mature trees.
2. Uneven-aged stands, necessitating a more intensive, base-line or comparison-tree selection method rather than the extensive selection per unit area as in strategy II.
3. Higher heritability for traits under selection and therefore a better chance of genetic gain in the orchard.
4. Non-precocious flowering habit (i.e. time can be saved by grafting).

Strategy Essentials

1. A minimum of 240 selections per breeding zone will be made to obtain the 216 clones required for each orchard.
2. The first-generation production orchards will be established with grafts according to the recommended design or one meeting specified minimum criteria.
3. A breeding orchard will be established for all selected trees.
4. Breeding will start with the onset of flowering in the breeding orchard.
5. Each pedigreed-family-evaluation plantation will be established at a minimum of three different locations according to the recommended test design.
6. Information from the pedigreed progeny tests (or open-pollinated-family tests) will be the basis for roguing the production orchards.
7. Selections from the progeny tests will form the foundation stock for the advanced-generation orchards.
8. The clonal option, which probably will use rooted cuttings, will be implemented whenever it is economically and biologically feasible, especially in the early stages of seed production in the orchards, in order to use the genetically improved seeds more efficiently.

Procedural Guidelines

SELECTION OF SUPERIOR TREES

A minimum of 240 trees (216 plus 24 extra selections to allow for graft incompatibility or scion mortality) will be selected for each clonal orchard to be established. The trees selected will be well distributed throughout the breeding zone. To minimize the selection of relatives, selected trees must be at least 300 m apart (unless prior approval is obtained from the TSFGU). The best phenotype will be chosen according to the selection criteria for the species. Usually, only scions will be collected from each tree; however, see the discussion below concerning the open-pollinated-test alternative.

FIRST-GENERATION PRODUCTION ORCHARD

The first-generation production orchard will be established with grafts from at least 216 different selected trees. The size of the orchard will depend upon the projected planting requirements for its planting zone and the estimated per tree production of viable seeds. No orchard should be smaller than eight hectares. The trees for all orchards currently being established or planned will be planted in a hexagonal pattern according to a permutated neighbourhood design (Figure 5). The hexagonal pattern provides equal spatial distribution for all trees. The permutated neighbourhood design has a number of advantages over other commonly used designs. In particular, it promotes the greatest number of outcrossings by surrounding each **clone** by ramets of six different clones. A computer program is used to allocate the clone numbers randomly, restricting the number of plantings between ramets of the same clone and the neighbours of each clone. For Ontario's program ramets of the same clone will be at least five planting spots apart. No two clones will be adjacent to each other more than once, hence the name "permutated neighbourhood".

Future orchards may have a single-tree, completely randomized block design, which will allow for a more even distribution of the trees remaining after roguing.

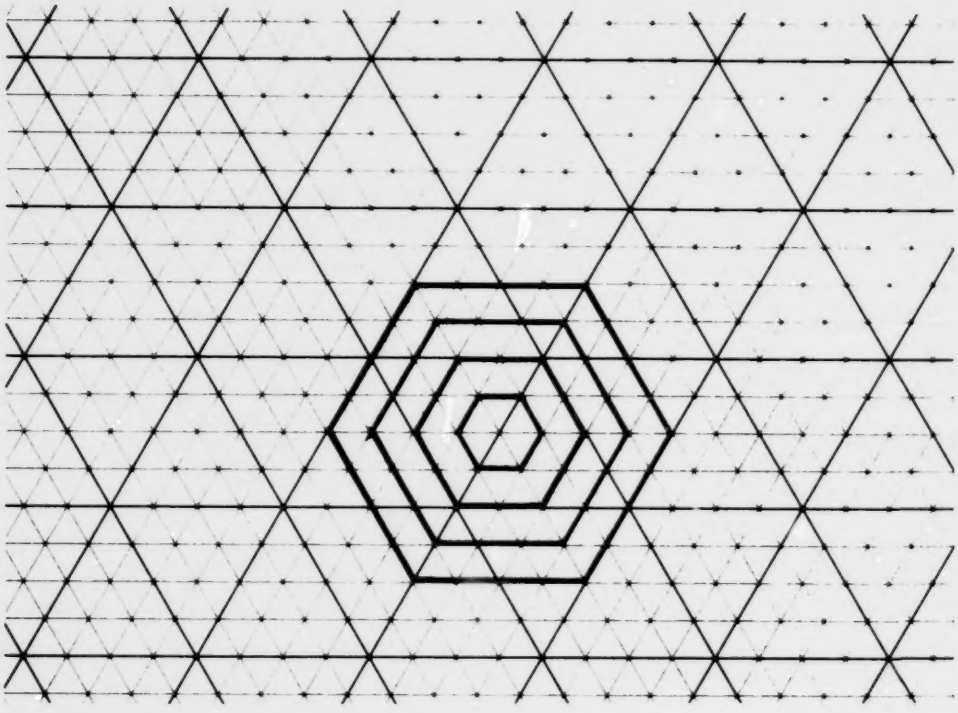
The criteria for site selection, site preparation and orchard management are detailed in the *Operational Guidelines For Tree Improvement* prepared by the TSFGU.

In the early life of the orchards, too few seeds will be produced to meet planting requirements. Therefore, if it is economically and biologically feasible, these early seeds should be used to grow donor stock for the production of cuttings for the clonal forestry program.

BREEDING ORCHARD

Three to five ramets of each selection will be planted in row plots to produce a breeding orchard. Breeding halls should be used to shorten the time to flowering and to improve the flowering capacity of the ramets. Early flowering of the breeding-orchard ramets is important in the clonal orchard approach because the crosses must be completed and the progeny tests established, grown and evaluated before the production orchard can be rogued.

Breeding will start with the onset of flower production. The breeding population will be sub-lined and one, or a combination of two, appropriate mating designs will be used for breeding within lines. The use of the sub-lines enables the breeder to eliminate inbreeding in future production populations. To reduce contamination of the production from unwanted genotypes, the breeding orchard should not be located near the production orchard.



a.

3	6	2	4	1	4
2	5	1	6	2	5
1	4	3	5	3	6

b.

Figure 5. *Clonal seed orchard design and block layout. (a) Permutated neighbourhood design. Each ramet is isolated by four rings of different clones. Any combination of two adjacent clones occurs only once in any specific direction. (b) Block layout for an eight hectare orchard. Each block contains 36 clones of 4 ramets each.*

PEDIGREED-FAMILY-EVALUATION PLANTATIONS (PROGENY TESTS)

The material for the progeny tests will be obtained from the controlled pollinations made in the breeding orchard. The primary purpose of the progeny tests will be to provide the majority of selections for the second-generation production and breeding populations. A secondary but important purpose will be to provide the basis for roguing the production orchard. In some species an additional reason for the tests will be to provide material for the clonal forestry program (Strategy IV). Each **full-sib** family will be planted in a single tree plot design on a minimum of three different field sites. Details on the establishment of these tests are being prepared and will be available as a procedural bulletin.

If not enough seeds are available from the controlled crosses or if better information is required on genotype x environmental interactions, the seedlings can be cloned and clonal-progeny tests established. Since these tests will be used for second-generation selections, enough clones per family must be produced so that the numbers of clones to select among are sufficient to provide a satisfactory selection differential.

OPEN-POLLINATED-FAMILY TEST ALTERNATIVE

An alternative to using pedigreed families to rogue the clonal orchard is to use open-pollinated-family tests. However, this alternative is acceptable only if certain biological criteria are met, and it is subject to various logistical constraints. (The TSFGU should be consulted prior to implementing this alternative.)

An important assumption in the use of open-pollinated tests is that the pollen contribution to a given mother-tree's cones is representative of the entire stand. This requirement precludes selection of single, isolated trees whose open-pollinated families are likely to have a high proportion of selfed-seeds. Seeds collected in years when the overall cone crop in the stand is sparse will also be an inadequate sample of paternal genotypes; this will have negative consequences not only for parent-tree evaluation but also for advanced generation selection.

Trees of the species for which the clonal orchard approach is recommended generally shed their seeds over a short period in late-summer or early-fall. This means that each selected tree needs to be visited *at least twice*, once for selection and scion collection and once for cone collection.

If the biological conditions are met, then the open-pollinated-family test alternative is advantageous because, 1) it will accelerate the orchard roguing substantially and 2) the information needed to rogue the orchard may be more accurate than that produced from a full-sib test using a compromising mating design.

ADVANCED-GENERATION PRODUCTION ORCHARDS

Second-generation and subsequent advanced-generation production orchards will also be clonal. Selections for the second generation will be made in the progeny tests as soon as reliable family ranks are available. (To reduce the time between generations, it will be essential to promote early flowering in the breeding orchards so that crosses can be made and the progeny tests established quickly.) The selection will be made from the various sub-lines created by the crossing program in a way that eliminates inbreeding in the production orchard. The design and layout of the production orchard will be decided when the selections are made.

STRATEGY IV — CLONAL FORESTRY

The third of the three intensive strategies, the clonal forestry approach, is proposed not only as a source of improved material through the first generation but also as a source of material for all subsequent generations. As indicated in Strategies II and III above, the clonal option may be used to amplify the initial limited quantities of seeds that will be produced in young orchards. The clonal option, in some cases, may also be an internal part of a species' overall improvement program, providing additional gains above those obtainable in the seedling-based orchard program. Finally, a clonal program may be the sole source of genetically improved stock for regeneration of certain species. It is in this latter context that clonal forestry may be treated as a separate strategy.

In the clonal forestry approach for most species, trees will be selected from natural stands, plantations, and local or external improvement programs. Scions will be collected from these trees and grafted into a breeding orchard. In some situations it may also be possible to collect open-pollinated cones at this time, subject to the same conditions discussed in the clonal seed orchard strategy above. As the breeding orchard starts to flower, controlled pollinations will be made according to a specific mating design. The resultant seeds will be germinated and the **juvenile** seedlings will be used as donor stock for the production of rooted cuttings. Some trees of each clone will be placed in field test plantations where, after several years of testing, the best families and the best clones within families will be identified. Any surplus rooted cuttings beyond those rooted for testing will be used for production plantations. The clones selected in the field test will be vegetatively propagated and placed in the breeding orchard. Genetically improved planting stock for plantations will be produced by either "full-sib expansion" or **"hedge orchards"** (or a variant thereof), both described in greater detail below. The flow chart in Figure 6 illustrates typical operations in the clonal strategy. A modified version of this approach is used with poplar in order to take advantage of some of the genera's favourable characteristics; the program is described further in this section.

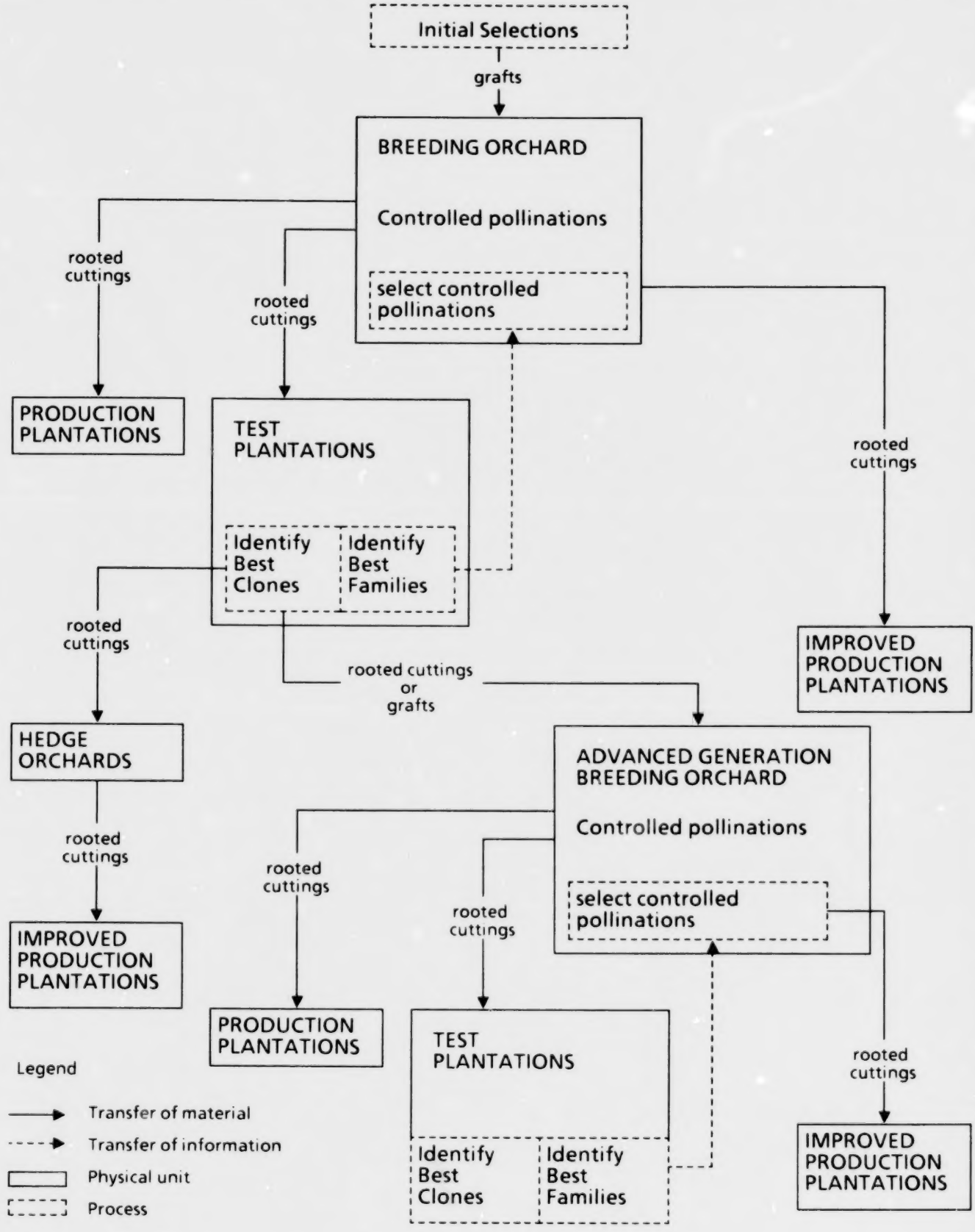


Figure 6. *Breeding and production strategy for clonal forestry (for poplar clonal strategy see Appendix III-1.).*

Clonal forestry is recommended for species that have several of the following characteristics:

1. Ease of rootability, or other form of non-sexual propagation (e.g. tissue culture).
2. Difficulty in being reproduced by seed.
3. Insufficient quantities of seeds to supply the artificial regeneration program.
4. Regeneration requirements insufficient to merit a conventional seed orchard program.
5. Need to produce specialty stock (e.g. blister-rust-resistant white pine hybrids).

Clonal forestry offers many advantages over the production of seeds in conventional seed orchards. Some of the advantages are:

1. Ease of propagation: some species can be reproduced more readily by rooting cuttings than by germinating seeds and raising seedlings.
2. Capture of favourable genetic variation: all individuals of a clone are genetically identical and therefore favourable combinations of genes are not lost in the offspring due to sexual **recombination**.
3. Cost-effective propagation of expensive genotypes: for example, hybrid stock may be very expensive to produce via seeds but much less expensive when mass-produced by rooting cuttings.
4. Use of trees that are not sexually prolific: these trees would be removed from a production orchard since they produce small quantities of seeds but should be used in a clonal program.
5. Capture of favourable correlation for traits that normally exhibit a negative correlation (a ''correlation breaker''). For example, specific gravity generally decreases as growth rate increases, but occasionally high specific gravity and fast growth rate are found in the same tree; this combination of traits can be mass-produced by clonal propagation but would be lost in a seed orchard program.

Strategy Essentials

1. The number of trees selected for any particular clonal forestry program will depend upon the source of material, the purpose for which the cuttings will be used, and the size of the area to be planted with clonal material.
2. All selections will be grafted into a breeding orchard.
3. One breeding orchard can contain several breeding zones for each species, several species and several species hybrids of each species.
4. Breeding will start with the onset of flowering in the breeding orchard.
5. Each clonal-progeny test will be established at a minimum of three different locations according to the recommended design.
6. Information from the clonal-progeny tests will determine which parents will be selected for production of additional seeds for the donor stock that will supply cuttings for production plantations.
7. The best clones will be selected from the clonal progeny tests for the establishment of hedge orchards (where feasible) and advanced-generation breeding orchards.
8. Clones for production plantations will be mass-produced either from cuttings obtained in a hedge orchard or by the serial propagation of rooted cuttings.

SELECTION OF SUPERIOR TREES

The number of trees selected in this program will not be fixed; it will depend upon factors such as the purpose for which the cuttings will be produced and the type of material selected. For example, if the cuttings were to be used to regenerate a large planting zone, the number of selections would be larger than if they were to be used for a restricted planting zone. The selections will be made in natural stands or plantations of native species. If **exotics** or other species were of interest for hybridization, then the selections could come from Ontario or be imported from other provinces or countries. Scions will be collected from each tree selected, grafted, and put in a breeding orchard.

BREEDING ORCHARD

Three to five ramets from each tree selected will be planted in row plots to produce an initial breeding orchard. Breeding halls should be constructed to shorten the time to flowering and to improve the flowering capacity of the ramets. Several breeding zones for each species and several species and species hybrids can be established in one breeding orchard since all of the seeds will be obtained through controlled pollinations and pollen contamination will not be a problem.

Breeding will start with the onset of flowering. The way in which the breeding populations will be developed will depend on the purpose of the program. In a small, standard regeneration program, breeding will follow the procedures described earlier, but if the purpose is to develop disease resistance or a superior hybrid, the breeding will be done differently.

Once the results are available from the clonal-family tests, the breeding orchards will be used for selective breeding by crossing the superior parents in order to obtain additional seeds for donor seedlings from which to produce rooted cuttings for production plantations. These advanced-generation breeding orchards may need to be expanded, on a per-select-clone basis, in order to produce the quantities of seeds needed to fill the stock requirements of a given planting program. This could entail regrafting selections in the original breeding orchard or collecting more scions from the selections in the field tests.

CLONAL PROGENY TESTS

The trees for the clonal progeny tests will originate from controlled pollinations in the breeding orchard. Seeds from the crosses will be germinated, and the juvenile seedlings will be used as donors to obtain rooted cuttings. Tests will be established in a single tree plot design at a minimum of three different forest locations. Details on the establishment of these tests are being prepared and will be released as a procedural document.

The best families and the best clones within families will be identified after the family ranks have become relatively stable. The parents of the best families will be used for selective breeding, and the best clones will be put through one of the mass propagation regimes (see below) for production plantations, and also into advanced-generation breeding orchards for future crossing work.

ALTERNATIVE I — MASS PROPAGATION BY FULL-SIB EXPANSION

This approach is currently a viable alternative for most of our major species and a number of secondary, but regionally important, species. Clones that have been progeny tested and found to be good **general combiners** or perform well in specific combinations are recrossed to produce large quantities of seeds. The resulting seedlings are used as donor plants in a serial propagation program. Serial propagation consists of taking cuttings from a donor plant, rooting them, then, designating some or all of these as the next round of donor plants, taking cuttings from them, etc.. Thus, from a single seed the number of trees available for planting has been "expanded" from one to many. More details on the technique can be found in *Operational Guidelines For Tree Improvement*.

ALTERNATIVE II — MASS PROPAGATION FROM HEDGE ORCHARDS

At current levels of knowledge, this option is restricted to a very few amenable species and situations, and much development is still needed. However, unlike full-sib expansion, hedge orchards offer a means to fully exploit all of the genetic variation, and to mass produce selected, elite individual clones.

Hedge orchards may be established with elite clones selected from the clonal progeny tests or with clones that are simultaneously being placed in field tests. The clone is propagated by rooting of cuttings, or occasionally by grafting, and after establishment in the orchard, is continually top pruned to form a low dense hedge approximately 0.5 m high. The effect of hedging is to retard physiological **maturation** of the plant, and hence retain the easy rootability which is generally a juvenile characteristic.

The sole purpose of a hedge is to produce cuttings for mass propagation programs. Several ramets per clone may be lined-out to expand the production capability. Several breeding zones for each species, and several species and species hybrids can be established in one hedge orchard, since pollen contamination is not a problem.

GENETIC RESOURCES MANAGEMENT

A number of different genetic implications exist between artificial and natural regeneration systems. Care must be taken in the management of the genetic base of each program to ensure sufficient future variability. This provides not only a buffer against as yet unknown insect or disease problems, but also provides the basis for additional breeding progress. The strategies described earlier in this chapter are consistent with good genetic management.

A different set of conditions and problems than those indicated above arises in the production phase of tree improvement programs. In order to avoid potential problems such as an insufficient number of clones in seed orchards and plantations, or overproduction of select clones or families, it is necessary to develop specific rules that will be in effect for all species. Standards will be established that will outline (1) the maximum number of ramets or seedlings per clone or family that can be produced, (2) the minimum number of clones or families to be planted in each production plantation, and (3) the maximum proportion of any production plantation that should be devoted to a particular clone or family.

STANDARDS FOR SPECIES PROGRAMS

This chapter outlines in point form the strategies to be followed by the province for each species listed in Table 1. Orchard requirements for the major species, based on current projections, are given in Table 2. Specific procedural details (for example, spacings) may differ slightly among the species designated for a given strategy. The silvical characteristics of the major species which influenced the choice of strategy are discussed in Appendix II.

These strategies will become effective immediately and will be subject to review at least every five years. However, if new pertinent information or technology becomes available in the interim, programs will be modified, if at all possible.

1. Strategy I, the basic program, will apply to all species that are artificially regenerated. This program will be de-emphasized for primary species as soon as genetically improved stock from intensive programs is available.
2. Strategy II, the seedling seed orchard approach, will be used for black spruce and jack pine improvement in the first generation. A typical program is shown schematically in Figure 7.
3. Strategy III, the clonal seed orchard approach, will be used for white spruce and white pine improvement. A typical program is shown schematically in Figure 8. Clonal orchards of black and white spruce established or started in the past with inferior designs will be managed and utilized as effectively as possible.
4. Strategy IV, the clonal forestry approach, will be used for tamarack, Norway spruce, larch, and blister-rust-resistent white pine hybrids as well as certain local programs for white spruce and white pine. (Refer to general schematic in Figure 6. Time frames may vary dramatically depending on species.)
5. The clonal forestry option will be aggressively pursued as an adjunct to seed orchard programs in all species that are biologically amenable to clonal propagation techniques.
6. A modified Strategy IV, the clonal forestry approach, will be used in the poplar program (Appendix III).
7. A modified Strategy III, a clonal seed orchard, will be used for black walnut improvement (Appendix IV).

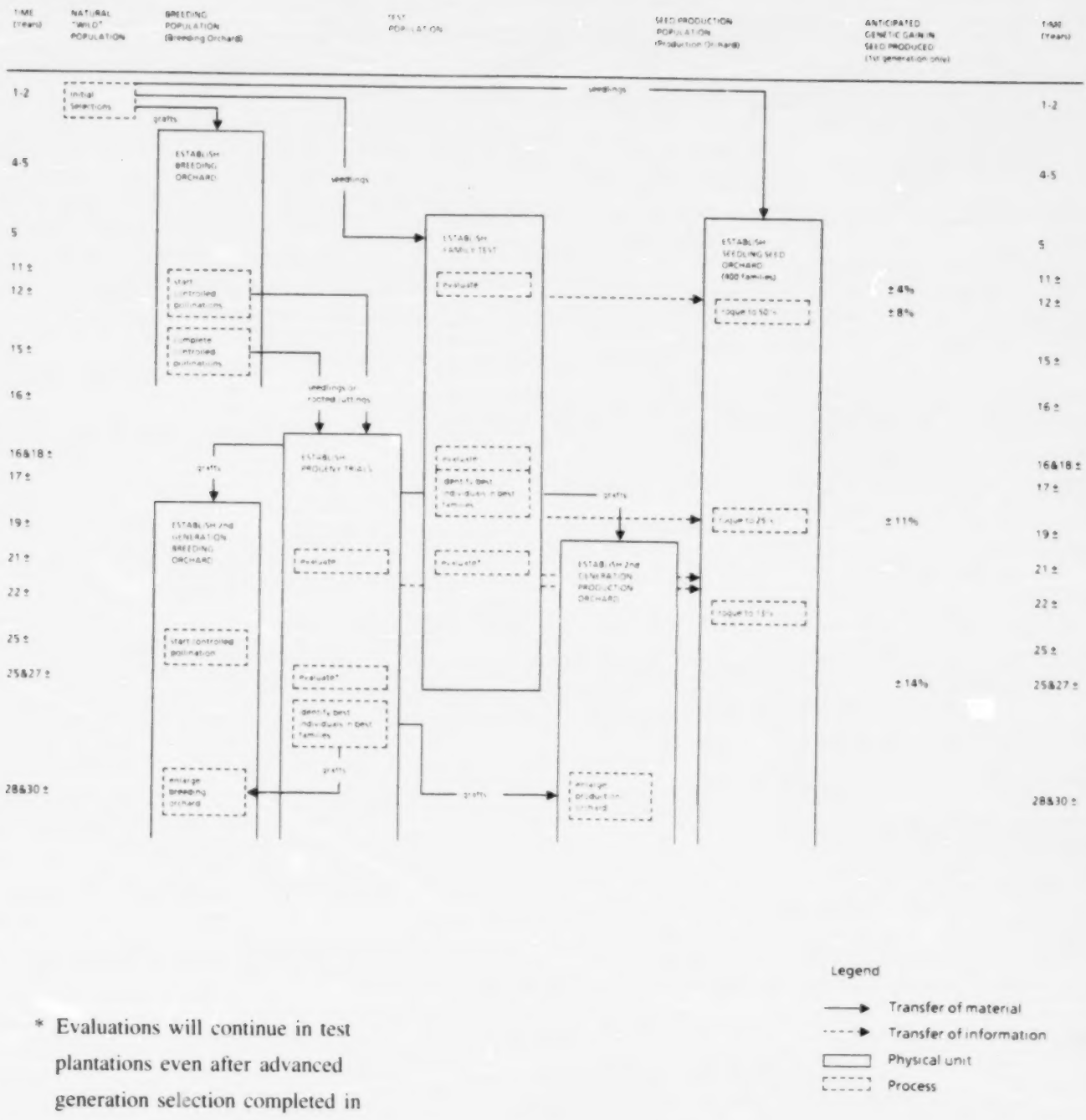
Table 2: Number of Seed Orchards and Total Area Required for each Principal Species

Region	Species			
	Sb # (ha)	Pj # (ha)	Sw # (ha)	Pw # (ha)
Northwestern[1]	12(60)	6(48)	6(48)	
North Central[2]	6(97)	2(31)	2(11)	
Northern	5(132)[1]	4(59)[1]	2(38)[3]	
Northeastern[1]	2(26)	5(70)	2(16)	3(24)
Algonquin[1]	—	—	1(10)	3(24)
Eastern[3]	—	—	1(12)	3(31)
Central[1]	—	—	1(12)	3(31)
Southwestern[1]	—	—	—	1(8)
Province	25(315)	17(208)	15(147)	13(118)

1 Program existing or plans in place.

2 Based on current regional projections: plan under development.

3 Based on seed required to maintain current stock production.



Legend

- Transfer of material
- Transfer of information
- Physical unit
- Process

* Evaluations will continue in test plantations even after advanced generation selection completed in order to monitor family rankings.

Figure 7. *Typical seedling seed orchard strategy for black spruce or jack pine (Strategy II).*

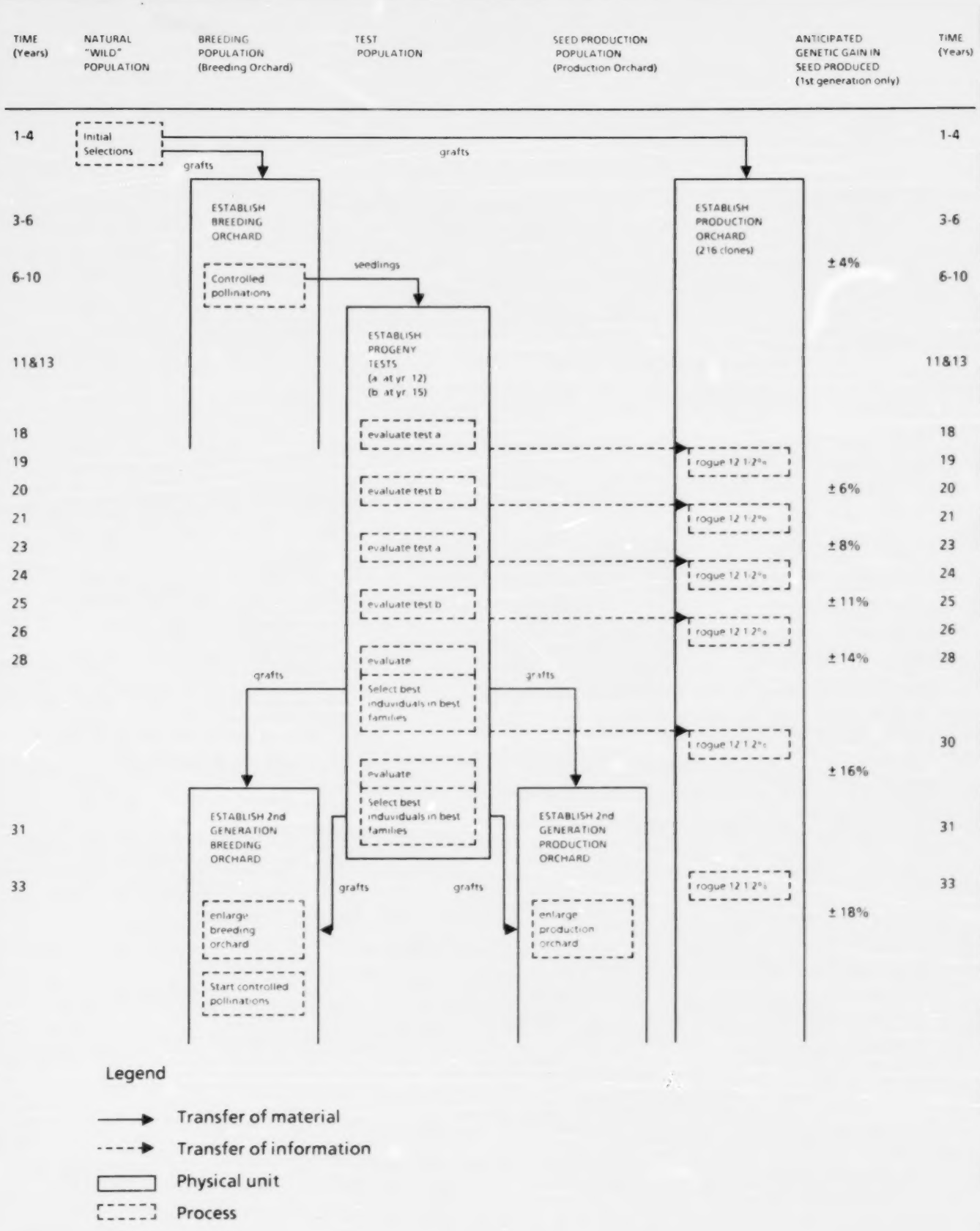


Figure 8. *Typical clonal seed orchard strategy for white spruce or white pine (Strategy III).*

ECONOMICS OF TREE IMPROVEMENT

Tree improvement is not only expensive, but it is also a long-term venture. However, most economic analyses have shown that with as little as a three per cent gain in volume, tree improvement is economically justifiable. In all of the production seed orchards proposed in this report, a minimum four per cent genetic gain is projected; following testing and roguing, a genetic gain in the range of 16 per cent or more is obtainable.

Several elements affect the profitability of seed orchard programs. Economic factors such as interest rates and product prices are critical values in the case of long-rotation species (50 years or more); they strongly influence any particular program design. However, the shorter the rotation the more important the program design and the smaller the improvement that is needed to justify the program economically. If planting and silvicultural management for producing improved stock are restricted to the best sites, the goals required for profitability will be easier to attain. The larger the planting program, the more economical it is to establish a hectare of production plantation and the less the improvement needed to earn a satisfactory return on the investment, since many of the costs of the seed orchard program are fixed.

EXPECTED COSTS AND BENEFITS

COSTS

Table 3 summarizes total estimated program costs for both the seedling seed orchard strategy and for the clonal seed orchard strategy. The figures shown are a compilation of actual program costs in some regions and projections of expected costs for operations not yet completed. (A breakdown by individual components and operations of the establishment and annual maintenance costs is given in Appendix VI Tables.)

The total cost of the seedling seed orchard is approximately 22 per cent higher than the clonal seed orchard for a 8-ha orchard. These cost differences are due to the additional size of the breeding orchard and to the family test requirements of the seedling seed orchard approach. The simplified projections used in construction of the table do not account for future inflation.

BENEFITS

Among the objectives listed in preceding sections was the improvement of traits such as form, wood properties, especially specific gravity, growth rates, and broad adaptability. Gains in each of these traits will have substantial economic impact, depending on the particular species and end use. However, it is difficult to quantify the economic values of most of these traits, and economic analyses of tree improvement have tended to concentrate on volume gains.

Table 3: Estimated Total Cost[1] of Program Based on an Eight Hectare Seed Orchard

	Establishment Costs	Measurement Costs	Total Annual Costs[2] 30-Year Life Span	Total Annual Costs[2] 40-Year Life Span	Total Cumulative Costs 30-Year Life Span	Total Cumulative Costs 40-Year Life Span
Seedling Seed Orchard						
Production Orchard	$135 460	$9 000[3]	$432 900	$549 900	$577 360	$694 360
Breeding orchard	23 835		18 500	23 500	42 335	47 335
Family test	25 285	7 500	148 000	188 000	180 785	220 785
Progeny test	35 400	8 439	148 000	188 000	191 839	231 839
TOTAL					992 319	1 194 319
Clonal Seed Orchard						
Production orchard	160 100		432 900	549 900	593 000	710 000
Breeding orchard	12 890		14 800	18 800	27 690	31 690
Progeny test	35 400	8 439	148 000	188 000	191 839	231 839
TOTAL					812 529	973 529

1. Based on 1983 expeditures and projections in 1983 dollars. (See details in Appendix Tables VI-1 to VI-4).
2. Operating life span of the production orchard - actual span from establishment would be approximately 37 and 47 years, respectively. Annual costs for breeding orchard and tests were carried over the same periods for the sake of simplicity. Actually the period of maintenance for these components will be considerably less.
3. Roguing costs ($3,000 three times).

Two ways of demonstrating the impact of volume gains are shown in Table 4. This table shows, for increasing amounts of genetic gain, (1) the reduction that could be made in the area cut without reducing the yield and (2) the increase in volume that could be obtained without increasing the area cut. Depending on the particular role an organization has in respect to regeneration, processing, or a combination of the two, one approach may be much more appropriate than the other. However, because interest rates have a significant impact on economic decisions, the usual approach is to consider the *rate* of volume growth, instead of absolute volume increase. An increase in growth rate brings a given volume closer to the present, hence profits are realised earlier. The economic analyses that follow examine two models, savings on area cut and increased revenue due to a shorter rotations.

Table 4: Effect of Genetic Gain on Volume Production Assuming a Status-Quo 100 cunits/ha.

Percentage Genetic Gain	Area Needed to Produce 100 cunits (hectares)	Volume Produced per Hectare (cunits)
0	1.00	100
4	.96	104
8	.92	108
12	.88	112
16	.84	116
20	.80	120

ECONOMIC ANALYSES

Since few data exist from past tree improvement experiences in Ontario, many assumptions must be made in order to produce a model that analyzes the economic effectiveness of tree improvement. Listed below are the major assumptions that apply to both the "area cut" and "rotation age" scenarios. Additional details including calculation methods are given in Appendix VI.

- The model is based on a black spruce seedling seed orchard program.
- The costs of the program are as shown in Table 3 for a seedling seed orchard with a 30-year production life. There is no-built-in inflation on annual maintenance.
- All other costs, e.g. site preparation, tending, harvesting, etc. are the same for both un-improved and improved plantings. The additional cost of tree improvement is solely in producing seeds.
- The genetic gains and the seed production schedule are as shown in Table 5. (More detailed information on anticipated seed production will be found in Appendix V.)
- All seeds produced can be used. Planting density is at 2500 trees/hectare.

The first analysis examines the potential economic benefits that might accrue from savings on regeneration costs. In order to supply the same volume of timber, less area of genetically improved plantations would be needed than if the plantation originated from unimproved seeds. Since less total area needs regeneration, the savings in regeneration costs are a benefit of using genetically improved seedlings.

Table 6 shows the discounted costs and benefits in the "area cut" model, under several combinations of interest rates and seed-to-seedling ratios (S/S), assuming regeneration costs of $1250/hectare for 2:1 S/S and $1500/hectare for others. This table demonstrates clearly the impact of both seed usage and interest rates on the profitability of the program. If seeds are used efficiently, then tree improvement would remain profitable even at rates as high as 12 per cent. Conversely, direct seeding (e.g. 50:1 seed/seedling ratio) would not be economically justified at any of the given rates. At interest rates above 6 per cent and with the existing practices in some nurseries, use of improved seeds for production of bare-root stock also would not be justified.

The second analysis shows the economic benefits in terms of the value of the final product at a shortened rotation age. *Additional* assumptions for this model:

- Comparison is made to:

  Case 1 - Unimproved, natural black spruce on site 1 forest harvested at age 80 and yielding 179 m^3/ha.

  Case 2 - intensively managed plantation on site class 1A yielding 300 m^3/ha at age 50.
- The value of one cubic meter of black spruce wood converted to paper is $192 at the end of the rotation. (1983 STATS CAN figure of $540 per tonne at .355 tonne/m^3).
- Pulp yields from improved trees will be similar to yields on which the above figures were based.

Table 5: Black Spruce Seedling Seed Orchard Program Schedule of Activities, Cost and Results

Year	Activity (in addition to annual maintenance)	Cost (M)	Viable Seed (millions)	Genetic Gain %
0	Establishment	160.7	0	0
1		15.7	0	0
2		15.7	0	0
3		15.7	0	0
4		15.7	0	0
5		15.7	0	0
6		15.7	0	0
7	Measure Family Test	18.2	0	0
8	Rogue Orchard	18.7	2.48	8
9		15.7	2.48	8
10		15.7	2.48	8
11		15.7	2.48	8
12	Measure Family Test	18.2	2.48	8
13	Rogue Orchard	18.7	3.76	11
14		15.7	3.76	11
15		15.7	3.76	11
16		15.7	3.76	11
17	Measure Family Test	18.2	3.76	11
18	Rogue Orchard	18.7	8.72	14
19		15.7	8.72	14
20		15.7	8.72	14
21		15.7	8.72	14
22		15.7	8.72	14
23		15.7	8.72	14
24		15.7	8.72	14
25	Measure Family Test	18.2	8.72	14
26	Rogue Orchard	18.7	7.04	16
27		11.7	7.04	16
28		11.7	7.04	16
29		11.7	7.04	16
30		11.7	7.04	16
31		11.7	12.72	16
32		11.7	12.72	16
33		11.7	12.72	16
34		11.7	12.72	16
35		11.7	12.72	16
36		11.7	12.72	16
37		11.7	12.72	16
		719.6	225.20	

*Figures taken from Table 3 and Appendix Tables VI-1 to VI-4.

Table 6: Present Net Worth of a Single Black Spruce Seedling Seed Orchard: Regeneration Cost Saved with Increased Yield on Fewer Areas (Millions of Dollars)

Interest Rate		Seed/Seedling Ratios 2:1	5:1	10:1	20:1	50:1
3%	benefits	3.803	1.268	0.634	0.317	0.127
	costs	-0.495	-0.495	-0.495	-0.495	-0.495
	Net	3.308	0.773	0.139	(0.178)	(0.368)
6%	benefits	1.819	0.606	0.303	0.152	0.061
	costs	-0.383	-0.383	-0.383	-0.383	-0.383
	Net	1.436	0.223	(0.083)	(0.138)	(0.322)
9%	benefits	0.931	0.310	0.155	0.078	0.031
	costs	-0.322	-0.322	-0.322	-0.322	-0.322
	Net	0.609	(0.012)	(0.167)	(0.244)	(0.291)
12%	benefits	0.508	0.169	0.085	0.042	0.017
	costs	-0.285	-0.285	-0.285	-0.285	-0.285
	Net	0.223	(0.116)	(0.200)	(0.243)	(0.268)

The second analysis is appropriate for an organization which does everything itself from start to finish, i.e. from collecting seeds through to selling the product. Tables 7 and 8 show the net present values for this model both for an 80-year old site class 1 stand and for a projected 50-year old site class 1a intensively managed plantation.

Not surprisingly, table 7 shows that for the longer rotation age (80 years) interest rates are a sensitive factor in the net profitability. While seed usage plays a role in the net present benefits (NPB) at a given interest rate, it appears to have less an impact than does interest rate. None-the-less, the analysis demonstrates that genetically inproved seeds need to be used efficiently. The intensively-managed-plantation case (Table 8) shows a generally more attractive financial picture, with positive NPBs under the majority of S/S and interest combinations. Comparisons between Tables 7 and 8 should be made with caution, since the 50-year old plantation case also represents intensive management, hence additional costs beyond those encountered in the less-intensively managed situation.

The two most important points shown in these simple economic analyses are:

1) Tree improvement is an economically justifiable investment over a wide range of conditions.
2) Genetically improved seeds must be used as efficiently as possible to maximize the return on that investment.

Table 7: Present Net Worth of a Black Spruce Seedling Seed Orchard: Additional Final Product Resulting from the Use of Genetically Improved Stock (Millions of Dollars)

Case 1

Interest Rate		Seed/Seedling Ratios 2:1	5:1	10:1	20:1	50:1
3%	benefits	22.753	9.094	4.547	2.274	0.909
	costs	-0.495	-0.495	-0.495	-0.495	-0.495
	Net	22.258	8.599	4.052	1.779	0.414
6%	benefits	2.502	1.001	0.500	0.250	0.100
	costs	-0.383	-0.383	-0.383	-0.383	-0.383
	Net	2.119	0.618	0.117	(0.113)	(0.283)
9%	benefits	0.238	0.095	0.048	0.024	0.010
	costs	-0.322	-0.322	-0.322	-0.322	-0.322
	Net	(0.084)	(0.227)	(0.272)	(0.298)	(0.312)
12%	benefits	0.023	0.009	0.005	0.002	0.001
	costs	-0.285	-0.285	-0.285	-0.285	-0.285
	Net	(0.262)	(0.276)	(0.280)	(0.283)	(0.284)

Table 8: Present Net Worth of a Black Spruce Seedling Seed Orchard: Additional Final Product Resulting from the Use of Genetically Improved Stock (Millions of Dollars)

Case 2

Interest Rate		Seed/Seedling Ratios				
		2:1	**5:1**	**10:1**	**20:1**	**50:1**
3%	benefits	54.429	21.772	10.886	5.443	2.177
	costs	-0.495	-0.495	-0.495	-0.495	-0.495
	Net	53.934	21.277	10.391	4.948	1.692
6%	benefits	13.353	5.341	2.671	1.335	0.534
	costs	-0.383	-0.383	-0.383	-0.383	-0.383
	Net	12.970	4.958	2.288	0.952	0.151
9%	benefits	2.721	1.088	0.544	0.272	0.109
	costs	-0.322	-0.322	-0.322	-0.322	-0.322
	Net	2.399	0.766	0.222	(0.050)	(0.213)
12%	benefits	0.543	0.217	0.109	0.054	0.022
	costs	-0.285	-0.285	-0.285	-0.285	-0.285
	Net	0.258	(0.068)	(0.176)	(0.231)	(0.263)

SUPPORTIVE RESEARCH

Although we now have enough basic information to confidently initiate tree improvement programs, many important questions still need to be answered in order to make these programs more efficient and accurate, and to reduce their costs.

Some examples of the types of research that are needed as support for the operational program are listed below. Some may appear very basic, but all have definite practical applications, can provide financial savings and increased genetic gains, and can shorten the turn-around times for advanced generations.

POPULATION AND QUANTITATIVE GENETIC STUDIES

- analysis of designs for seed orchards, progeny tests, and clonal trials
- estimation of heritabilities and other genetic parameters
- determination of population architectures
- evaluation of advanced breeding strategies
- continuation or establishment of **provenance** and population trials
- evaluation of tradeoffs associated with early testing (quantitative analysis).

PHYSIOLOGICAL GENETIC STUDIES

- management techniques for seed orchards (e.g. internal water relations, moisture stress, nutrient regimes, hormone applications)
- **flower induction**
- variation in drought and frost resistance
- analysis and interpretation of wood-quality variation
- isozyme markers for such uses as certification of controlled crosses and other genetic materials
- rejuvenation and control of maturation state
- early testing (physiological analysis).

TREE BREEDING STUDIES

- evaluation of species hybrids
- evaluation of promising exotics
- breeding and testing for specific conditions or traits
- clonal propagation techniques.

STUDIES TO IMPROVE THE CLONAL FORESTRY PROGRAM

- development of better operational rooting procedures
- improvement of bud initiation and development on young seedlings (especially pines)
- control of bud break via environmental and chemical control (especially white spruce).

APPENDIX I

Glossary

Adaptation: A process of evolutionary (genetic) adjustment that fits populations to their environment.

Allele: An alternative form of a particular genetic locus; there may be one to several alleles of each gene in a population.

Asexual reproduction: Reproduction without fertilization, e.g. rooting of cuttings.

Breeding hall: A simplified greenhouse used to encourage plant material to flower in order to carry out controlled pollination work.

Breeding orchard: A collection of selected trees or species established primarily to obtain seed from controlled pollinations.

Breeding zone: A geographic area from which selections are made and interbred.

Character, Characteristic (Trait): The measurable or describable expression of a gene or group of genes, e.g. tree height, stem and branch form.

Cline (adj. Clinal): A character gradient. A gradual and essentially continuous change of character in a series of contiguous populations, frequently, but not always, associated with gradual changes in an environment over distance.

Clonal forestry: Forest management practices that capitalize on the advantages provided by clones.

Clonal test: Evaluation of a genotype based upon its replicated performance.

Clone: A group of genetically identical organisms derived asexually.

Compatibility: The ability to form a successful union between scion and rootstock or the ability of two individuals, when crossed, to produce a viable seed.

Controlled pollination: Application of pollen from a known source onto a selected receptive female flower, all other pollens being excluded.

Cross-pollination: Transfer of pollen from one parent to a receptive female flower of another.

Cutting: A detached portion of a plant which, when treated, may form roots and a new, complete plant.

Diallel cross: A mating design that results from crossing all parents in all combinations, including selfs and reciprocal crosses.

Dioecious: Of a species having male and female flowers on separate plants.

Donor: A selected individual used to supply material for vegetative propagation.

Ecotype: A group of individuals within a species adapted to a particular environment.

Environment: All external conditions under which an individual's genes act to determine the individual's final appearance. Examples of environmental factors are climate, soil, moisture, stand composition and spacing.

Environmental variation: Variation in the appearance or performance of individuals resulting from their having been grown under different conditions (environments).

Exotic: A species introduced to an area outside its natural range.

Family: A group of related individuals. More narrowly, a group of siblings.

Family test: Evaluation of individuals based upon the performance of their relatives.

Flower induction: Stimulation of the onset of flowering or the increasing of the number of flowers.

Forest tree breeding: Application of the knowledge of genetics in order to develop genetically improved trees.

Forest tree improvement: Application of tree breeding and of silvicultural practices in order to produce improved trees.

Full-sibs: Two or more siblings with both parents in common.

Gene: The unit of genetic material that is converted to a biochemical product in the cell.

Gene pool: All the genes in a population. More specifically, the genetic basis for the population's continued evolution.

General combining ability: The average performance of offspring of an individual when that individual is crossed with a random sample of some designated population.

Genetic gain: The difference in the performance of offspring derived from selected parents and the average performance of the original, unselected parental population.

Genetic variation: Variation resulting from differences in genetic structure (genotype) of individuals.

Genotype: The actual genetic constitution of an organism.

Geographic variation: The variation resulting from genetic differences among native trees growing in different regions of their range.

Half-sibs: Two or more siblings with only one parent in common.

Hedge orchard: Cutting donors pruned low to retard maturation.

Heredity: The passing of genes from parent to offspring, which causes the offspring to resemble the parents.

Heritability: The proportion of the phenotypic variation that is due to genetic variation. A predictor of response to selection.

Hybrid: The offspring of two genetically different parents.

Inbreeding: Producing offspring from the mating of relatives.

Inbreeding depression: The loss ("depression") of vigour or fertility among the offspring of related individuals.

Incompatibility: Inability of scion and rootstock (q.v.) to unite successfully; or the inability of two individuals, when crossed, to produce a viable seed.

Interspecific hybridization: The crossing of individuals from different species.

Intraspecific hybridization: The crossing of genetically dissimilar individuals of the same species.

Isolation: The separation of a population from other populations. Isolation prevents or limits gene exchange.

Isozyme (Isoenzyme, Allozyme) studies: Method for looking at primary gene products (i.e. proteins) as observable single-gene markers.

Juvenility: A physiological state in which an individual exhibits characteristics different from those of the mature state, e.g. no flower production, leaf retention of hardwoods through winter, ease of rooting.

Local seed source: Source native to the locality in which the seedlings are to be grown.

Mating design: The planned pattern of controlled matings in some population(s) being bred.

Maturation: A physiological state in which an individual exhibits characteristics different from those of a young tree, e.g. production of reproductive parts, reduction in growth rate, mortality of some limbs.

Monoecious: Of a species having male and female flowers on the same plant but borne in different places.

Offspring: One or more first-generation decendants of an individual; progeny.

Outcrossing: The mating of unrelated individuals.

Partial-diallel cross: A diallel mating design in which some crosses, often selfs and/or reciprocals, are omitted. (See **diallel cross.**)

Pedigree: A record of the ancestry of an individual.

Periodicity: An average number of years between major seed crops.

Persistent cone habit: The tendency of cones to remain on the tree after the cone is mature.

Phenology: The study of relationships between plant development and seasonal climatic changes.

Phenotype: The appearance of an individual; a composite of the genotype and the environment and their interaction.

Planting zone: An area where planting stock from a given source can be planted.

Pollination: Deposition of pollen grains onto receptive parts of female flowers.

Population: A defined group of individuals.

Precocious flower habit: The characteristic of producing flowers at a very early age.

Production orchard: A plantation of selected seedlings or clones established primarily for seed production.

Progeny test: An evaluation of parents based upon the performance of their offspring.

Propagule: A reproduced organism that becomes an independent entity.

Provenance: The original geographic source of seed, pollen or propagules.

Ramet: A genetically identical plant derived asexually from one individual (the ortet).

Recombination: The process by which new combinations of genes, not present in the parental population, are obtained in the offspring.

Roguing: Systematic removal of undesirable individuals from a stand of trees or an orchard.

Rootstock: A plant onto which a scion is grafted.

Scion: A plant part, normally a branchlet, that is grafted onto another plant.

Seed orchard (production orchard): A plantation consisting of seedlings or clones established from selected trees, primarily for the production of seed of proven genetic quality.

Seed zone: An area delimited by geographic bounds, climate and growing conditions within which seeds may be moved freely without undue risk.

Seed-collection area: A relatively large, pure, uniform stand of mature or semi-mature trees and average or above-average form and vigour that is selected for the collection of source-identified seed from felled trees.

Seed-production area: A relatively small area that is medium-aged, sexually mature, and above average in form and vigour that is upgraded through roguing and management for the production and collection of source-identified seeds from standing trees.

Selection: The choosing of individuals or populations for particular characteristics.

Selective breeding: Controlled pollination amongst a group of trees selected for one or more desirable characteristics.

Selfing: Crossing with self; self-fertilization.

Serotinous cone habit: The seeds remain within a closed cone after the seeds mature.

Site region: An area delimited by geographic bounds and climate as described by G. A. Hills, "The classification and evaluation of site for forestry" (Ont. Dep. Lands and Forests, Div. Res., Res. Rep. 24, 1952; 41 pp.)

Stool bed: Hedge orchard, very low, usually applied to hardwoods.

Sub-line: Selections of superior trees that are divided into breeding groups. The breeding is done within, but not between, the groups to continue the sub-lines.

Superior tree (plus tree): A tree that appears phenotypically superior to the average.

Trait: A measurable expression of a gene or group of genes, e.g. height, stem form. (See **Character**.)

Tree breeding: See **Forest tree breeding**.

Tree improvement: See **Forest tree improvement**.

Vegetative propagation: The reproduction of genetically identical plants in a non-sexual manner, e.g. rooting of cuttings.

Vegetative propagule: A reproduced organism derived from a parent donor in an asexual manner.

Viability: The potential of pollen or seed to germinate.

APPENDIX II

Species Characteristics Affecting Strategy Selection

Black Spruce

SITE, SILVICAL AND GENETIC TRAITS

This species occurs over much of the forested area of northern Ontario. Although most of the black spruce grows on lowland sites, it does best on well-drained upland sites. On lowlands, it often occurs in pure stands, sometimes interspaced with tamarack; on uplands, it normally grows with jack pine, white spruce or poplar. The species is very shallow-rooted and susceptible to wind-throw. Black spruce is a pioneer species and large stands are usually the result of re-establishment after some disturbance such as fire.

In natural stands cone crops occur every four to seven years, although they appear to be more frequent in the northwestern part of the province. Cones can be collected over a long period owing to the species' **persistent** and semi-serotinous cone habit. Although much of the seed drops the first winter after the cone matures, some seed remains in the cone for one to two years. Under open-grown conditions, black spruce can start to flower at less than 10 years of age. This precocity and cone habit are consistent with the establishment of seedling seed orchards, at least for the first generation of improvement.

Insects often cause considerable losses of cones and seed, especially when the crop is light. Spruce budworm will often reduce the cone crop by destroying the flowers in early spring.

Although some variation may be found, black spruce is usually straight-stemmed and finely branched, and possesses very desirable wood, particularly for newsprint. This species already has generally good form and wood properties, and efforts are primarily directed towards increasing the rate of growth.

ECONOMIC IMPORTANCE

More black spruce is harvested than any other species in the province. Its long fibres make it one of the most desirable pulpwood species in the world. Since the statistics published by the province lump the data on white and black spruce together, the actual volume cut cannot be determined. However, in 1984/5, a total of 8.99 million cubic metres of mixed spruce, most of which was black spruce, was cut on Crown land. This accounts for 55 per cent of the total volume of conifers cut, or 43 per cent of the total volume of all species cut in Ontario during 1984/5. According to projections, the volume of black spruce to be cut will increase over the next 40 years.

ARTIFICIAL REGENERATION

More black spruce is planted in the province than any other species, and projections show that the number planted will continue to rise rapidly. The Northern Region alone is expecting to plant 38 million black spruce annually by the end of the 1980s.

Appendix Table II-1 shows the provincial seedling and seed requirements for black spruce from 1987 to 1991. This table shows a dramatic increase in production of bareroot and container stock as well as in seed required for direct seeding. A seed orchard program will be developed to meet provincial planting needs, but the seed for the direct seeding program will have to come from SPAs or SCAs. The expense of tree improvement prohibits the use of genetically improved seed for direct seeding, at least until the seed can be used more efficiently.

Table II - 1: Provincial Requirements for Black Spruce Seed and Seedlings from 1987 to 1991

Planting Year	Bareroot Stock (millions of trees)	Container Stock (millions of trees)	Direct Seeding (millions of seed)
1984 actual	8.293	40.005	179.1
1987	29.272	44.842	105.9
1988	31.167	47.220	105.9
1989	31.307	48.025	106.0
1990	31.867	46.890	106.0
1991	32.300	46.700	106.0

Based on February 1986 figures.

Jack Pine

SITE, SILVICAL AND GENETIC TRAITS

This fast-growing, short-rotation species occurs on many sites throughout northern and central Ontario. It performs best on well-drained, sandy loams. As a pioneer species, it often occurs in pure, even-aged stands as a result of natural seeding after wildfire. Though cone crops occur every two or three years, cones can be collected at any time since they are persistent and serotinous in habit. Jack pine starts to flower at an early age, and a significant number of cones can be collected from trees less than 10 years old. This precocity and cone habit are consistent with the establishment of seedling seed orchards, at least for the first-generation of improvement.

Jack pine is one of the province's most variable species. Stem and branch form as well as wood quality vary greatly. In most species these traits are strongly heritable and can be easily manipulated through genetics. It is anticipated that substantial improvements in the stem and crown form will be made in the first generation. The growth rate is also variable but has only low to moderate heritability; thus improvement of this trait is more difficult and requires more complex procedures. Growth will become a more important objective in later generations, when heritability can be increased by better control of our test environments.

ECONOMIC IMPORTANCE

By volume, jack pine is the second most important species harvested in Ontario. In 1984, 5.62 million cubic metres were harvested on Crown land; that constitutes 27.2 per cent of the total provincial cut, or 34.3 per cent of the total conifer cut. For companies such as Great Lakes Forest Products Ltd., Kimberly Clark Co. Ltd. and E. B. Eddy Forest Products Ltd., jack pine is a significant part of the total annual harvest. Projections show that the real volume of wood cut is likely to increase but that the percentage may drop owing to the increased cutting of poplar.

ARTIFICIAL REGENERATION

More than 60 per cent of the land artificially regenerated annually is planted or seeded with jack pine. The percentage fluctuates widely and is directly related to the incidence of wildfire on jack pine sites. Approximately 85 per cent of the area regenerated is direct-seeded and the rest planted.

Appendix Table II-2 shows the provincial requirements for jack pine seed and seedlings from 1987 to 1991. These requirements will strongly influence the size and scope of the tree improvement program. Unless the ratio of seeds used in direct seeding to numbers of plants established can be reduced substantially, using seed from intensive improvement programs for direct seeding cannot be economically justified.

Table II - 2: Provincial Requirements for Jack Pine Seed and Seedlings from 1987 to 1991

Planting Year	Bareroot Stock (millions of trees)	Container Stock (millions of trees)	Direct Seeding (millions of seed)
1984 actual	11.981	34.010	1 263.0
1987	11.544	45.298	1 414.0
1988	11.806	49.192	1 446.0
1989	12.892	49.315	1 500.0
1990	12.052	50.010	1 500.0
1991	11.882	50.764	1 500.0

Based on February 1986 figures.

White Pine

SITE, SILVICAL AND GENETIC TRAITS

White pine is economically important throughout the four southern regions of Ontario and in isolated areas throughout the northern part of the province. It normally grows in uneven-aged, mixed-wood stands, although in some places, such as Algonquin Park, it does occur in pure stands. It is long-lived and capable of good growth on a variety of sites ranging from well to poorly drained and can also do well on high-lime sites. In southern Ontario much of the gene pool has been severely depleted, and white pine remains only in small and scattered private woodlots or in plantations. In some parts of cen-

tral and eastern Ontario, there are natural stands of considerable size remaining.

White pine stems are often malformed and forked as a result of weevil attack, and trees in some environments also suffer damage from white pine blister rust. These two pests caused white pine to fall into disfavour with foresters for many years, and it is only recently, with more intensive silvicultural management, that the effects of these two problems are being overcome. As mentioned earlier, it may be possible to supply blister-rust-tolerant stock for high-risk areas.

White pines do not normally produce seeds in any quantity until they are at least 25 years of age. Cone crops are infrequent: they occur every three to seven years. Insects also cause considerable loss of cones and seeds, as experienced in the clonal orchard at the Orono Nursery. There is a very short period to pick the cones of white pine: if they are picked much before maturity, they shrivel, do not open, and do not produce viable seeds; if they are picked a month after maturity, most of the seed will have been dispersed.

The silvical characteristics of this species lend themselves to the clonal seed orchard approach. Since white pine grafts easily, several years can be saved from the time of the establishment to the time of seed production by grafting rather than raising seedlings. Moreover, the cone crop periodicity and the shortness of the collecting period make it very difficult to collect seeds from select trees in the wild for seedling seed orchards.

The stem and crown form of white pine both vary, although the rate of growth is the prime factor for selection and improvement. Studies of this species show it to be quite variable and suitable for genetic improvement.

ECONOMIC IMPORTANCE

White pine is the most highly valued lumber species in the province, as the superior quality of its wood makes it desirable for furniture and other fine wood products. In 1982, 529 000 cubic metres of white pine were cut on Crown land, accounting for 3.6 per cent of the total conifer cut, or 3.0 per cent of the total species cut in the province. This volume will likely remain static for many years. Although the percentage may be low, the economic value is high.

ARTIFICIAL REGENERATION

During the 1960s, the planting program for this species was very small; during the late 1970s, the number started to increase; projections into the early 1990s are shown in Appendix Table II-3. Most of the increase will be in the production of bareroot stock. This trend differs from black spruce and jack pine, where most of the increase will be in the production of container stock. The size of the direct seeding program is directly dependent upon the interest of the field staff. Production seed orchards are proposed for any planting zone that has an annual planting target of one million trees or greater.

Table II - 3: Provincial Requirements for White Pine Seed and Seedlings from 1987 to 1991

Planting Year	Bareroot Stock (millions of trees)	Container Stock (millions of trees)	Direct Seeding (millions of seed)
1984 actual	8.386	1.422	13.5
1987	6.193	1.365	12.1
1988	6.578	1.710	12.1
1989	6.598	1.420	12.0
1990	6.498	1.520	12.0
1991	6.477	1.570	12.0

Based on February 1986 figures.

White Spruce

SITE, SILVICAL AND GENETIC TRAITS

White spruce grows throughout the province and is normally found in uneven-aged, mixed-wood stands, although occasionally it occurs in small, pure patches. It is susceptible to late spring frosts when planted on large, clear-cut areas. White spruce lives longer than black spruce and can grow bigger, but it sometimes grows more slowly. It prefers well-drained, upland areas and is normally found on acid soils, but also grows well on alkaline soils like those found in southeastern Ontario. Planting problems such as "planting check", late spring frost and susceptibility to spruce budworm have reduced its desirability as a species for Ontario's artifical regeneration program.

In southern Ontario, much of the gene pool has been eliminated and white spruce remains only sporadically distributed throughout a few private woodlots and along the slopes of rivers and streams.

Most white spruce trees do not start to produce seed until the age of 15-20 years. The periodicity of the cone crop varies from one part of the province to another, but is normally between three and eight years. Insects often cause considerable losses in cone and seed yields, especially when the crop is light. If spruce budworm is present, it will also reduce the cone crop by destroying the flowers in early spring. Occasionally the flowers are damaged and the cone crop is reduced by spring frosts.

There is a very short time in which to pick cones of white spruce. Cones can be picked up to three weeks before maturity only if they are put in a cool, dry place where they can continue to ripen. But they must be picked within a few days of maturation because the seed drops very quickly. If the trees are felled for seed collection, they must be cut about one week before cone maturity to prevent the seeds from scattering when the trees hit the ground.

The silvical characteristics of this species lend themselves to the clonal seed orchard approach. White spruce can be easily grafted, and seed can be obtained several years sooner by grafting rather than raising seedlings. Moreover, the crop periodicity and the short time for collecting cones make it impractical to collect seed from select trees in the wild for seedling seed orchards.

White spruce is genetically diverse and suitable for genetic improvement. The stem and crown form vary and are a consideration in selecting superior trees, but the rate of growth is the prime factor for selection and improvement.

ECONOMIC IMPORTANCE

White spruce is valued primarily as a lumber species and is economically important throughout the province. Since black and white spruce statistics are combined in MNR reports, it is difficult to calculate the true importance of the latter in the province, but individual districts such as Hearst have a very heavy cut of white spruce.

ARTIFICIAL REGENERATION

During the 1960s this was the number-one species planted in the province, but because of planting problems, slower rate of juvenile growth, incidence of spruce budworm, and so on, white spruce has often been replaced by black spruce. Recently there has been a slight reversal of this trend, and more white spruce is now being requested for planting programs. Appendix Table II-4 presents seed and seedling requirements for this species to the year 1991.

Table II - 4: Provincial Requirements for White Spruce Seed and Seedlings from 1987 to 1991

Planting Year	Bareroot Stock (millions of trees)	Container Stock (millions of trees)	Direct Seeding (million of seed)
1984 actual	11.225	.077	23.4
1987	12.924	.820	8.2
1988	15.929	.480	10.7
1989	14.022	.300	9.5
1990	13.823	.345	9.5
1991	13.906	.320	9.5

Based on February 1986 figures.

APPENDIX III

Poplar Tree Improvement Program

SITE, SILVICAL AND GENETIC TRAITS OF NATIVE SPECIES

Trembling aspen, largetooth aspen, balsam poplar and eastern cottonwood are poplar species native to Ontario. Trembling aspen grows throughout the province. It is found on moist soils, but grows best on well-drained moist, sandy or gravelly loams. Largetooth aspen is confined to moister soils within the Great Lakes - St. Lawrence and Deciduous Forest Regions. Balsam poplar grows best on moist, fertile, low-lying ground throughout the Boreal and Great Lakes - St. Lawrence Forest Regions. Eastern cottonwood is found mainly along stream banks in the southern and eastern part of the Great Lakes - St. Lawrence Forest Region and in the Deciduous Forest Region.

Poplars are fast-growing, relatively short-lived trees supported by wide-spreading shallow root systems. Although they can occasionally produce abundant quantities of seeds early, seedlings require very specific environmental conditions to survive and grow. Most species reproduce naturally by means of suckers that arise from roots near the surface of the ground or by means of sprouts that originate from stumps. Thus, clonal reproduction is normal biology for this species.

Poplar species show large tree-to-tree (clone-to-clone) variation. The species hybridize easily and many of the interspecific hybrids show vigorous growth. In the hybrid poplar program, one of the parental species is commonly native to Ontario. Most can be easily multiplied through vegetative propagation by rooting stem cuttings or root suckers.

ECONOMIC IMPORTANCE

In the last 10 years, the volume of native poplar species cut has increased from 674 000 cubic metres to 1 650 000 cubic metres. This does not include the poplar harvested as "mixed hardwood". Poplar accounts for approximately 10 per cent of the total volume of wood harvested in Ontario. The demand is expected to increase with the advent of modernized pulp mills and technology development introducing new products such as composite board.

ARTIFICIAL REGENERATION

Most poplar stands cut or burned in northern Ontario are left to regenerate naturally. The areas planted are primarily abandoned farmlands throughout southern and eastern Ontario. Approximately 500 000 Carolina poplar clonal stock are produced annually. In addition, 500 ha of select hybrid clones are established each year in the Eastern Region. The size of the planting program will likely increase, given local wood requirements and suitable sites.

Strategy Essentials

1. Strategy IV - the clonal forestry approach will be used for the production of all poplar planting stock.
2. Clones for the poplar program are selected according to a given set of criteria.
3. Gene pool plantations and breeding orchards are established for native and exotic species.
4. Seedling and clonal trials are established to obtain suitable material for a variety of sites, environments and management systems.
5. Selected breeding is done according to a predetermined mating design.
6. Hedge orchards (**stool beds**) are established for all clones selected for production.
7. A minimum of 50 clones will be in production.
8. New clones will be introduced annually into the production program.
9. Carolina poplar production will be phased out by 1987.
10. Feasibility of clonal certification will be examined.

PROCEDURAL GUIDELINES FOR POPLAR

The tree improvement program emphasizes interspecific hybrids of poplar rather than the pure native species for production plantings. A modified version of Strategy IV will be followed for all poplar species to be artificially regenerated.

Criteria for Clonal Selection

The criteria for the selection of clones are, in order of importance, good rooting ability, resistance to frost, resistance to insects and diseases, fast growth, desired site tolerance, favourable response to intensive management, tolerance to specific management techniques, and desired biomass qualities.

Selection, Testing and Breeding

For native species as well as for selected exotic species, scions and seeds are obtained in order to establish breeding orchards and gene pool plantations. The best performing clones and seedlings are then identified and crossed according to a specific mating design. Seedling-pedigreed-family tests are established on a variety of sites and environments. These tests are evaluated, the best trees identified, cloned and **clonal** screening **tests** established, again on a variety of sites and environments and under different management systems. In some instances, cuttings from the original selections are obtained and placed directly into test plantations. The best clones from these tests are re-established in hedge orchards to provide material for production plantations. Appendix Figure III-1 illustrates the steps in this program.

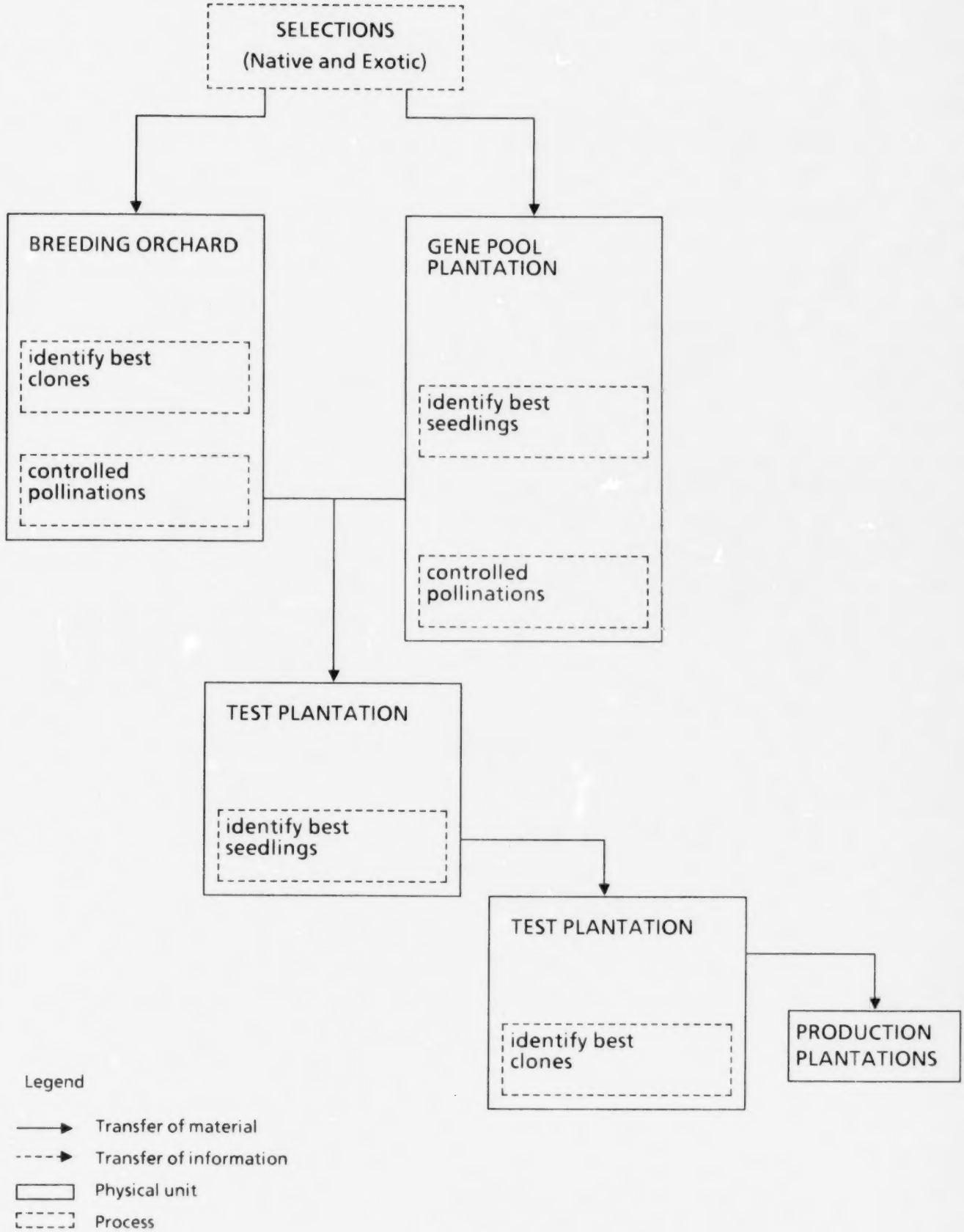


Figure III-1. *Breeding and production strategy for poplar.*

Production Plantations

A *minimum* of 50 clones will be available at all times for production plantations. Based on test results, about five new clones will be introduced into the production program annually. With the introduction of new clones, the propagation of Carolina poplar will be phased out by 1987. Sufficient ramets per clone will be established in hedge orchards to supply all cuttings required. The clones selected for production plantations will be chosen according to their site suitability, the plantation system and the desired end product. The feasibility of clonal certification for hybrid poplars will be determined as soon as possible.

Clonal Certification

In clonal forestry, it is essential to be able to accurateiy identify the clones being mass-produced for production plantations. The ability to correctly identify clones becomes increasingly important as more material is grown by the private sector. The clonal program for poplar is the only one sufficiently advanced that certification may soon be both feasible and appropriate. The benefits, logistics and expense of clonal certification for poplar will be examined and appropriate recommendations made.

APPENDIX IV

Black Walnut Tree Improvement Program

SITE, SILVICAL AND GENETIC TRAITS

Black walnut occurs naturally only in the southwestern part of the province (see Appendix Figure IV-1), where it grows on deep, fertile, well-drained soils. It is generally found as one or a few stems; rarely does it form as much as five per cent of a stand. Many trees are found on lawns and along roadsides, and it is difficult to tell whether they are from local populations or were imported by the settlers from New York and Pennsylvania many years ago. Given a good site and good management, this species can produce veneer-size trees in less than 50 years.

The sporadic distribution of trees means that seeds produced and collected are most probably selfed. Few seeds result from self-fertilizations, and more important, the seedlings grow slowly. Thus to obtain good planting stock, it is important to produce out-crossed seed by establishing production orchards. Uncontrolled cutting of black walnut on private lands caused a severe erosion of the genetic base. Thus, the tree improvement effort is also a much needed gene conservation program.

ECONOMIC IMPORTANCE

Black walnut may be Ontario's most valuable species on a per-stem basis due to its great value for furniture. Individual trees have been sold for thousands of dollars. If enough trees are planted and properly managed, this species could not only maintain the furniture industry in southern Ontario but help it to grow.

ARTIFICIAL REGENERATION

Currently about 350 000 trees are planted on 500 ha of land every year. This rate is expected to remain stable because there are only a limited number of planting sites available.

Strategy Essentials

1. A modified Strategy III - the clonal seed orchard approach will be used.
2. The remaining selections will be made by 1987.
3. The establishment phase of the orchard will be completed by 1988.
4. The production orchard will also serve as the breeding orchard.

PROCEDURAL GUIDELINES FOR BLACK WALNUT

One orchard will satisfy the planting needs for this species. The first-generation orchard will be a clonal orchard. It will be established at St. Williams Nursery in Simcoe District. The orchard will consist of three ramets of each of the 200 families planted in the permutated neighbourhood design. The six hectare orchard will meet the current planting targets. One half of the required selections have already been made. The rest of the selections will be made by 1987 and the establishment phase of the orchard will be completed by the fall of 1988. The production orchard will also serve as a breeding orchard.

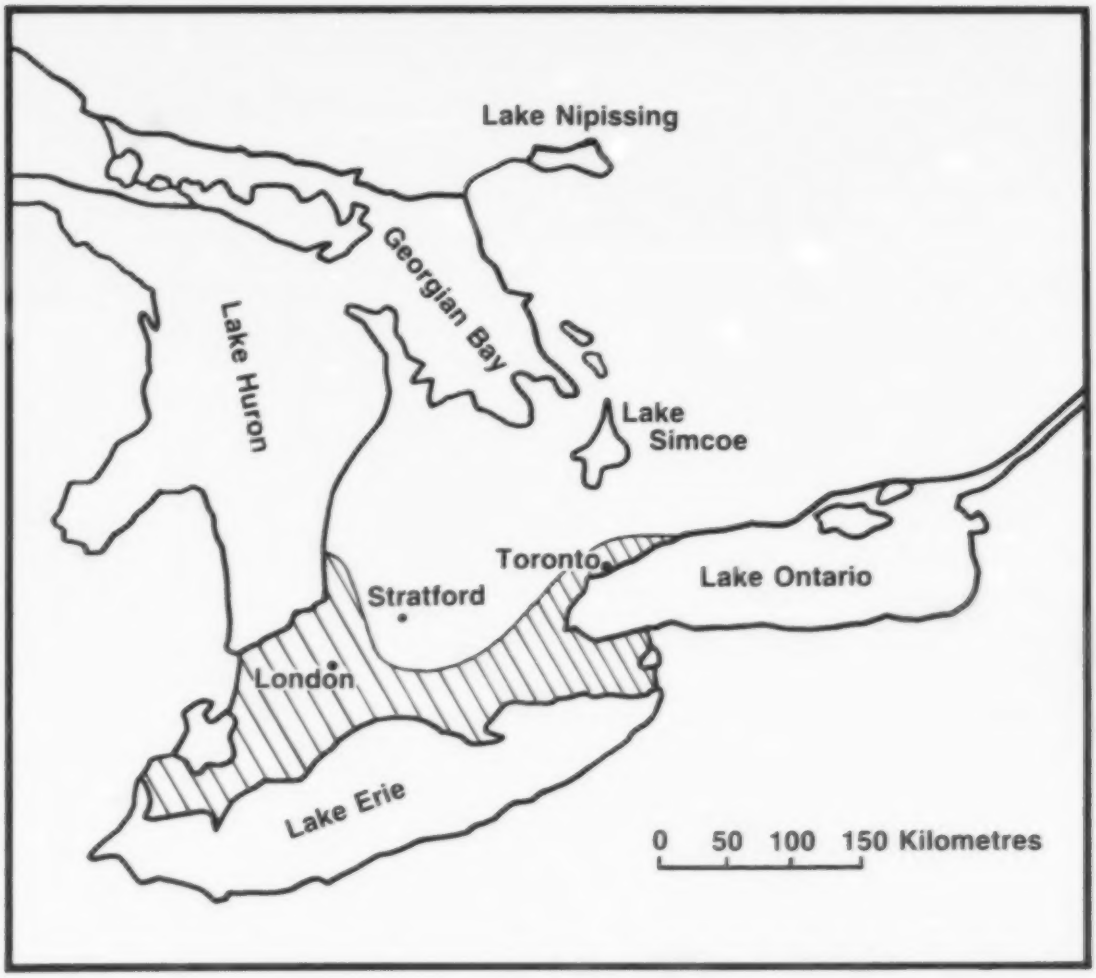


Figure IV-1. *Natural distribution of black walnut.*

APPENDIX V

Anticipated Seed Production in Orchards for the Four Major Tree Improvement Species

Table V - 1: Anticipated Seed Production in a Black Spruce Seedling Seed Orchard

Initial orchard specifications:		
	Spacing between cluster centres	= 4m x 4m
	Number of clusters per hectare	= 625
	Number of trees per hectare	= 2500
	Number of families	= 400
	Number of replications	= 50

	Number of Years Following Field Establishment					
	1-7	8-12	13-17	18-25	26-30	31+
No. of trees per hectare	2 500	1 250	625	625	313	313
No. of trees in orchard	20 000	10 000	5 000	5 000	2 500	2 500
Cones per tree		100	200	350	450	600
Viable seed per cone		10	15	20	25	30
Viable seed per tree		1 000	3 000	7 000	11 250	15 000
Viable seed per orchard (MM) (based on 75% trees flowering, and a 3-year periodicity)		7.50	11.25	26.25	21.09	38.12
Viable seed per hectare (MM) (amount of seed produced every third year)		0.94	1.41	3.28	2.64	4.77
Annual viable seed per hectare (MM)		0.31	0.47	1.09	0.88	1.59
Annual viable seed per 8-hectare orchard (MM)		2.48	3.76	8.72	7.04	12.72

Table V - 2: Anticipated Seed Production in a Jack Pine Seedling Seed Orchard

Initial orchard specifications:	Spacing between cluster centres = 4m x 4m Number of clusters per hectare = 625 Number of trees per hectare = 2500 Number of families = 400 Number of replications = 50									
	Number of Years Following Field Establishment									
	6	8	10	12	14	16	18	20	22	24
No. of trees per hectare	2 500	1 250	1 250	1 250	625	625	625	625	625	313
No. of trees in orchard	20 000	10 000	10 000	10 000	5 000	5 000	5 000	5 000	5 000	2 500
Cones per tree	35	50	90	110	120	150	170	170	180	180
Viable seed per cone	15	18	20	23	23	25	25	27	30	30
Viable seed per tree	525	900	1 800	2 530	2 760	3 750	4 250	4 590	5 400	5 400
Viable seed per orchard (MM) (based on 75% trees flowering, and a 2-year periodicity)	7.88	6.75	6.75	18.98	10.35	14.06	15.94	17.21	20.25	10.13
Viable seed per hectare (MM) (amount of seed produced every second year)	0.98	0.85	0.85	2.37	1.30	1.78	1.99	2.15	2.53	1.27
Annual viable seed per hectare (MM)	0.49	0.43	0.43	1.19	0.65	0.89	1.00	1.08	1.26	0.64
Annual viable seed per 8-hectare orchard (MM)	3.94	3.38	3.38	9.49	5.18	7.03	7.97	8.60	10.13	5.06

Table V - 3: Anticipated Seed Production in a White Pine Clonal Orchard

Initial orchard specifications:		
	Design	= Permutated neighbourhood
	Layout	= Hexagon
	Spacing	= 6 m
	Number of trees per hectare	= 320
	No. of clones	= 216
	No. ramets per clone	= 12
	Total no. of trees	= 2592
	Area planted	= 8 ha

	Number of Years Following Field Establishment						
	8-12	13-17	18-23	24-26	27-28	29-31	32+
No. of trees per hectare	320	320	320	240	160	111	74
No. of trees in orchard	2 592	2 592	2 592	1 944	1 296	900	600
No. of clones in orchard	216	216	216	162	108	75	50
Cones per tree	50	100	200	250	300	375	450
Viable seed per cone	20	25	30	30	35	35	38
Viable seed per tree	1 000	2 500	6 000	7 500	10 500	13 125	17 100
Viable seed per orchard (MM) (based on 75% trees flowering, and a 3-year periodicity)	1.944	4.860	11.664	10.935	10.206	8.859	7.695
Viable seed per hectare (MM) (amount of seed produced every third year)	0.243	0.608	1.458	1.377	1.276	1.107	0.962
Annual viable seed per hectare (MM)	0.081	0.202	0.493	0.456	0.425	0.369	0.321
Total viable seed per 8-hectare orchard (MM)	0.648	1.620	3.890	3.645	3.402	2.953	2.565

Table V - 4: Anticipated Seed Production in a White Spruce Clonal Orchard

Initial orchard specifications:		
	Design	= Permutated neighbourhood
	Layout	= Hexagon
	Spacing	= 6 m
	No. of trees per hectare	= 320
	No. of clones	= 216
	No. of ramets per clone	= 12
	Total no. of trees	= 2592
	Area planted	= 8 ha

	Number of Years Following Field Establishment					
	8-12	13-19	20-22	23-24	25-27	28+
No. of trees per hectare	320	320	240	160	111	74
No. of trees in orchard	2 592	2 592	1 944	1 296	900	600
No. of clones in orchard	216	216	162	108	75	50
Cones per tree	100	175	250	400	550	800
Viable seed per cone	10	15	20	23	27	32
Viable seed per tree	1 000	2 625	5 000	9 200	14 850	25 600
Viable seed per orchard (MM) (based on 75% trees flowering, and a 3-year periodicity)	1.944	5.103	7.290	8.942	10.024	11.520
Viable seed per hectare (MM) (amount of seed produced every third year)	0.243	0.638	0.911	1.118	1.253	1.440
Annual viable seed per hectare (MM)	0.081	0.213	0.304	0.373	0.418	0.480
Total viable seed per 8-hectare orchard (MM)	0.648	1.701	2.430	2.980	3.341	3.840

APPENDIX VI

Program Component Cost and Methods for Economic Analysis Presented in the Text

This appendix will show the methods used to calculate the benefits and costs given in Tables 6, 7 and 8.

1. A production orchard does not operate at a set level of gain and seed production for the duration of its life. Both genetic gain and seed production will occur at different levels for different periods. One simplified anticipated schedule is shown in Table 5 (in text) and indicates there are five such periods referred to below as Genetic Gain (GG) periods.
2. The following variables are used in calculation under both the "Area" and Rotation Age" models.

   TSP_n = Total seed production in the nth period

   S/S = Seed/seedling ratio

   GG_n = Length of nth genetic gain period

   S/ha = Planting density (2500 in all cases shown)

   GGP_n = Genetic Gain Proportion in nth period

   $= \frac{g}{1+g}$ where g = % genetic gain (4, 8, 11 and 16%)

For the "Area Model":

3. Calculate the Monetary Savings for not planting a given area:

$$AP_n = \frac{TSP_n \times GG_n}{S/S \times S/ha}$$

$$AS_n = AP_n \times GGP_n$$

$$MS_n = AS_n \times PC/ha$$

where: AP_n = area that can be planted with improved stock during period 'n';

AS_n = area that doesn't need planting because of planting improved stock during period 'n';

MS_n = monetary value of savings from not planting AS_n during period 'n';

PC/ha = planting costs per hectare: includes growing stock, site preparation and planting. A value of 1,250 dollars per hectare was used for the 2:1 seed to seedling ratio (container stock). A value 1,500 dollars per hectare was used for all other seed to seedling ratios (bareroot stock).

4. Calculate the present value of the Monetary Savings over the operating life of the orchard (37 years). These values are shown in Table 6 (in text) as "benefits".

$$PV = \sum_{n=1}^{5} \left[\left\{ \frac{MS_n}{GG_n} \quad X \quad \frac{[(1 + r)\ GG_n] - 1}{r\ (1 + r)^{GG_n}} \quad X\ (1 + r)^{N-t_n} \right\} \div (1 + r)^N \right]$$

where: N = operating life of orchard = 37 years

t_n = number of years from establishment to beginning of n^{th} period

r = interest rate

For the "Rotation Age" Model:

5. For assigning a monetary value to shortening the rotation age, first calculate the new rotation ages at the different levels of genetic gain shown in Table 5:

$NR_n = OR\ X\ (1 - GGP_n)$

where: NR_n = new rotation in n^{th} period

OR = old rotation age

6. Calculate the value associated with one hectare of timber converted into final product form.
V/ha = $192. X yield

7. Calculate the present value of V/ha harvested at the end of rotation for both unimproved and improved rotation ages. There are (in our models) four different genetic gain levels, so there will be four new rotation ages. The differences between the old rotation values and the new rotation values are the additional revenues (R_n) associated with planting improved stock.

8. Working through 5, 6 and 7, using the example of an 80 year old rotation on site class 1 (179 m^3/ha)* we have:

$NR_1 = 80\ X\ [1- (.08/1.08)] = 74$

$NR_{2,3,4,5,} = 72, 70, 60$ and 69 respectively.

at 3%:	PV-unimp	PV-imp	R_n	Where $PV = FV/(1+p)^x$
	$3230	$3857	$ 627	and x = OR or NR_n
	"	4091	861	r = .03
	"	4341	1111	FV = $192 x 179 m^3/ha
	"	4471	1241	= $ 34,368

9. Calculate total revenues associated with each Genetic Gain period:

$$TR_n = R_n\ X\ \frac{TSP_n}{S/S\ X\ S/ha}$$

10. Calculate the present value of the total revenue benefits accrued over the life of the orchard substituting TR_n for MS_n/GG_n in the formula shown in step 4 above. These values are shown in tables 7 and 8 (in text) as benefits.

*Plonski, 1974. *Normal Yield Tables (Metric) for Major Species of Ontario.* Ontario Ministry of Natural Resources. 40 pages.

For Both Models:

11. Calculate the present value of all costs over the life of the orchard (shown in Tables 7 and 8 in text):

$$\text{Total present cost} = EC + AOC \times \frac{(1 + r)^N - 1}{p(1 + r)^N}$$

where EC = establishment costs

AOC = annual operating costs

r,N = as above

12. Net present values are the difference between present values of benefits and present values of costs as shown in Tables 6, 7 and 8.

Table VI-1: Average Costs of Establishment for Seedling Seed Orchards and Clonal Seed Orchards [1] (based on an 8 ha orchard)

Activity	Seedling Seed Orchard Costs	Clonal Seed Orchard Costs
Superior tree selection	49 500	48 000
(seed and scion collection)	(@ 110/sel.)[2]	(@ 200/sel.)[3]
Seed extraction and process	5 850	
	(@ $13/sel.)	
Production of stock	6 750	54 000
	($250/M)	($15/graft)
Sorting	1 120	
Staking and layout	2 040	1 000
Preparation of site	16 000	16 000
	(@ $2 000/ha)	(@ $2 000/ha)
Planting	12 800	2 400
Mapping	2 700	500
Assessment of survival	1 500	1 000
Weed control, cover crop	3 800	3 800
Irrigation	25 000	25 000
Fencing, gates	1 800	1 800
Other orchard management	5 000	5 000
Management plan	1 600	1 600
Total establishment costs	135 460	160 100
Annual operating costs	11 700	11 700

1 Average 1983 costs based on 1982/83 figures from Northwestern Region as well as 1984/85 figures from Northern Region.

2 Select 450 trees to get 400 for orchard. Some have reported costs as high as $200/selection.

3 Select 240 trees to get 216 for orchard.

Table VI-2: Estimated Costs of Establishing a Breeding Orchard

Activity	Seedling Seed Orchard Costs	Clonal Seed Orchard Costs
Size of breeding orchard	0.5 ha	0.25 ha
Grafting:		
450 selections, 3 ramets	$20 250 (@ $15/graft)	
240 selections, 3 ramets		$10 800 (@ $15/graft)
Site prep. (@$2 000)/ha	1 500 (@ 0.75 ha)	800 (@ 0.4 ha)
Planting (@$1.10/graft)	1 485	790
Weed control, cover crop	300	200
Irrigation	nil - orchard is assumed to be in a nursery or adjacent to another orchard	
Other orchard management	300	300
Total cost of establishment	$23 835	$12 890
Annual operating costs	500	400

Table VI-3: Estimated Cost of Establishing a Progeny Test

Activity	Cost
Number of trees	(20 000)
Number of hectares	(8)
Controlled pollinations	$9 720 (over 6 years)
Stock production (@$300/M)	6 000
Planting (@$200/M)	4 000
Staking and layout	3 000
Preparing a site (@$1 000/ha)	8 000
Mapping (@$335/ha)	2 680
Survival assessment (@$0.05/tree)	1 000
Management	1 000
Total costs	35 400
Annual operating costs	4 000
Measurement costs (3 times) (measure 853 trees/person-day, @120/person-day)	2 813 (X3)

Assumptions: The 8 hectare progeny test is for 216 parents. A total of 540 crosses are made with 36 individuals per cross.

Table VI-4: Estimated Costs of Establishing a Family Test

Activity	Cost
Stock production (16M @$300/M)	$ 4 800
Sorting (@$2.80/family)	1 125
Staking and layout	3 000
Preparing a site (8ha @$1 000/ha)	8 000
Planting (16M @$200/M)	3 200
Mapping (8 ha @$420/ha)	3 360
Survival assessment (16M @$0.05/tree)	800
Management	1 000
Total establishment costs	25 285
Measurement costs (3 times) (measure 853 trees/person-day, $120/person-day)	2 500 (X3)
Annual operating costs	4 000

Assumptions: 400 families are tested, requiring 40 individuals per family including 4 spares.
The 16M trees require 6.4 hectares of planting area.

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